NEW

# UNDERSTANDING The Brain

UNRAVELLING THE NERVOUS SYSTEM

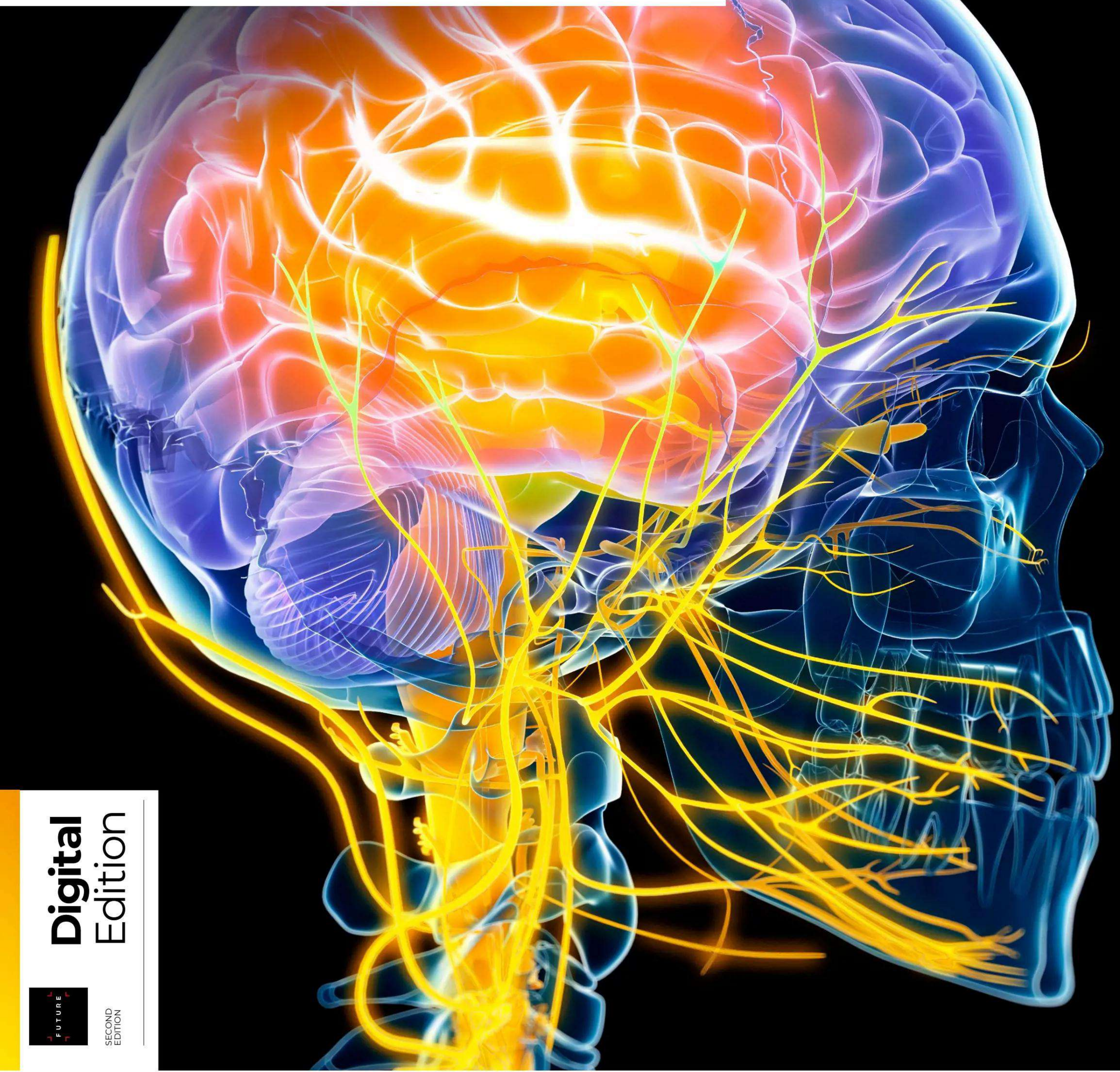
THE SCIENCE OF PAIN

WHY DO WE SLEEP?

HOW OPTICAL ILLUSIONS WORK

IS IT POSSIBLE TO SEE YOUR THOUGHTS?

THE SCIENCE OF EMOTIONS



Digital Edition

FUTURE

SECOND EDITION

# Welcome

There's a catchy quote about the brain that goes something like, "If the human brain were so simple that we could understand it, we would be so simple that we couldn't." Though the quote's origin has been attributed to a variety of clever people over the years, it still rings true today: our brains are vastly complicated organs that even the brainiest experts in their feld struggle to comprehend. In this book, we look at everything from the brain's physical structure and biochemical functions, to human and animal psychology, our emotions, dreams, and more. Enjoy!

FUTURE

# UNDERSTANDING
# The Brain

**Future PLC** Quay House, The Ambury, Bath, BA1 1UA

**Editorial**
Editor **Ben Biggs**
Senior Art Editor **Duncan Crook**
Compiled by **Charles Ginger & Andy Downes**
Head of Art & Design **Greg Whitaker**
Editorial Director **Jon White**
Managing Director **Grainne McKenna**

**Cover images**
Getty

**Photography**
All copyrights and trademarks are recognised and respected

**Advertising**
Media packs are available on request
Commercial Director **Clare Dove**

**International**
Head of Print Licensing **Rachel Shaw**
licensing@futurenet.com
www.futurecontenthub.com

**Circulation**
Head of Newstrade **Tim Mathers**

**Production**
Head of Production **Mark Constance**
Production Project Manager **Matthew Eglinton**
Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Managers **Keely Miller, Nola Cokely, Vivienne Calvert, Fran Twentyman**

Printed in the UK

**Distributed by** Marketforce – www.marketforce.co.uk
For enquiries, please email: mfcommunications@futurenet.com

**Understanding The Brain Second Edition (HIB6015)**
**© 2024 Future Publishing Limited**

We are committed to only using magazine paper which is derived from responsibly managed, certified forestry and chlorine-free manufacture. The paper in this bookazine was sourced and produced from sustainable managed forests, conforming to strict environmental and socioeconomic standards.

All contents © 2024 Future Publishing Limited or published under licence. All rights reserved. No part of this magazine may be used, stored, transmitted or reproduced in any way without the prior written permission of the publisher. Future Publishing Limited (company number 2008885) is registered in England and Wales. Registered office: Quay House, The Ambury, Bath BA1 1UA. All information contained in this publication is for information only and is, as far as we are aware, correct at the time of going to press. Future cannot accept any responsibility for errors or inaccuracies in such information. You are advised to contact manufacturers and retailers directly with regard to the price of products/services referred to in this publication. Apps and websites mentioned in this publication are not under our control. We are not responsible for their contents or any other changes or updates to them. This magazine is fully independent and not affiliated in any way with the companies mentioned herein.

FUTURE

Connectors. Creators. Experience Makers.

Future plc is a public company quoted on the London Stock Exchange (symbol: FUTR)
www.futureplc.com

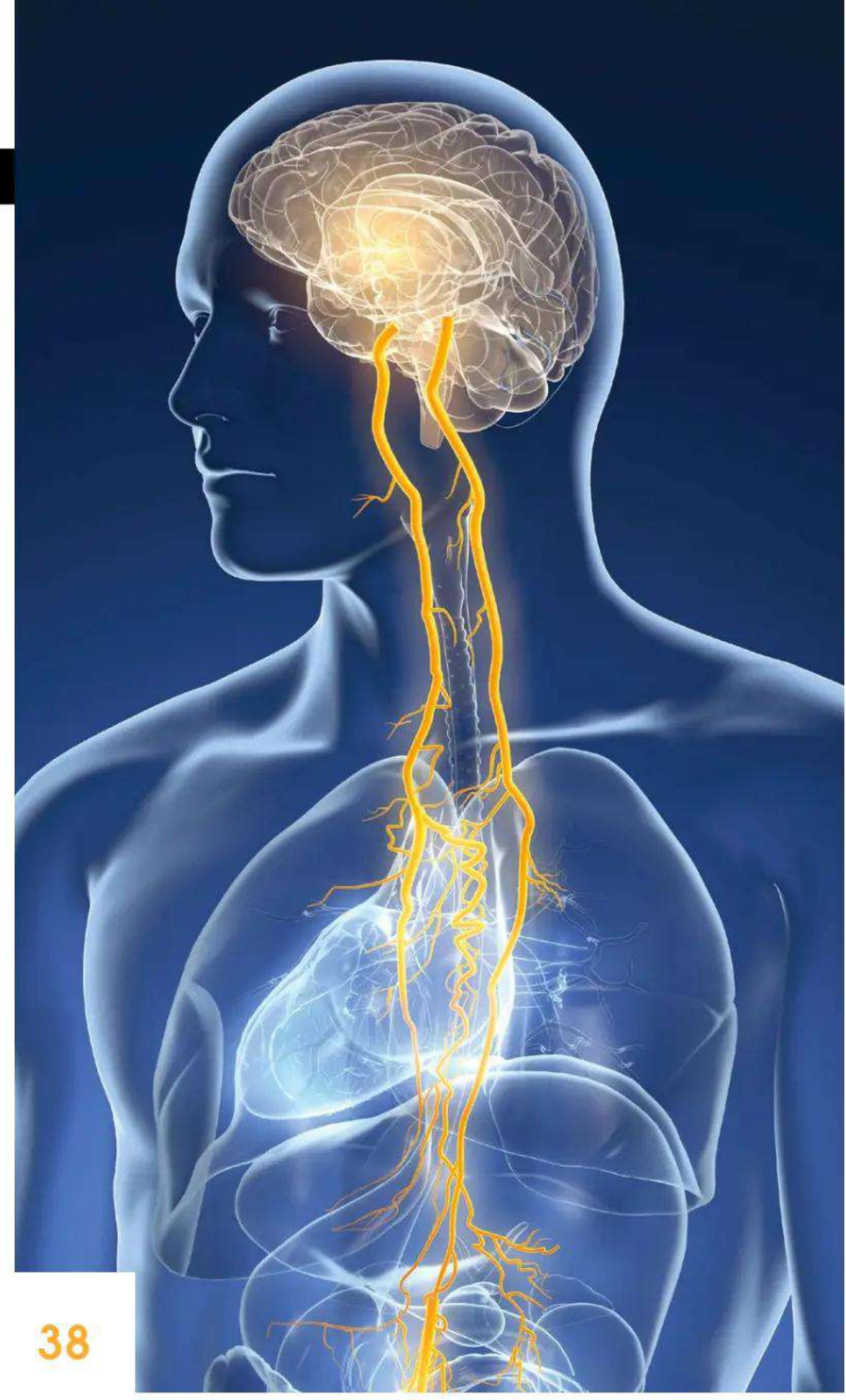
Chief Executive Officer **Jon Steinberg**
Non-Executive Chairman **Richard Huntingford**
Chief Financial and Strategy Officer **Penny Ladkin-Brand**

Tel +44 (0)1225 442 244

Widely Recycled

ipso. For press freedom with responsibility

# Contents



38

## BIOLOGY


**10 You brain explained...**
The human brain is both the most mysterious and complex entity in the known universe

**14 What is muscle memory?**
How neural shortcuts in your brain make practised activities feel familiar

**16 Unravelling the nervous system**
Explore the electrically charged network composed of billions of cells that coordinates your thoughts, feelings and actions from head to toe

**24 The gut-brain axis**
How does the bacteria in your gut act like a 'second brain'?

**26 The science of pain**
Our internal alarm system works around the clock to keep us safe from harm

**32 What is the blood-brain barrier?**
How this gateway controls molecules that pass from the blood into the brain

**33 Piturity gland up close**
What does this hormone factory do and why couldn't we live without it?

**34 The science behind your accent**
How an accent is generated by the brain and shaped over time

**38 Ten weird things you never knew about your brain**
Discover the science and psychology behind the brain's fascinatingly quirky and unique design


## SLEEP


**48 Why do we sleep?**
The science behind your body's ability to power down at night

**50 Nightmares, phobias and everyday fears explained**
We tend to fear what we don't understand. But learning about our fears can make them much less frightening

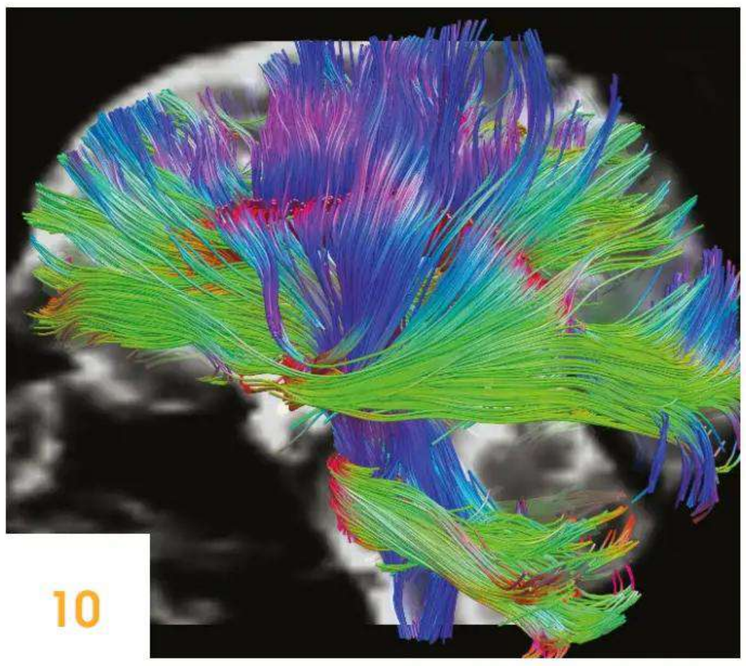

## PSYCHOLOGY


**60 The science of emotions**
How our ancient brains evolved the perfect way to keep us safe

**66 How to catch a lie**
It's all in the body language

**70 How does hypnosis work?**
Discover the science behind hypnosis, how it's used to alter behaviour and even assist in surgery

48



10

26

**74 How we learn**

Forget artificial intelligence, the human brain is the original neural network

**80 How optical illusions work**

Why and how do our eyes play tricks on our brain?

**86 Spirit in the psychology**

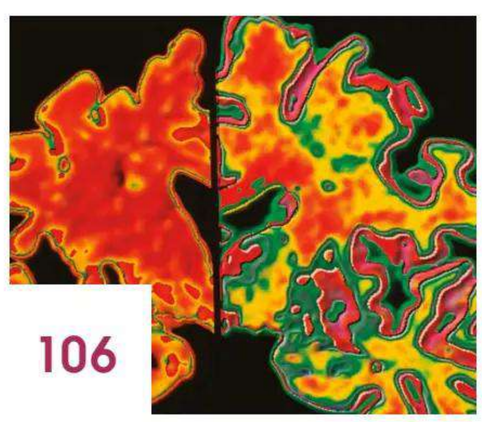
Parapsychologist Dr Ciarán O'Keeffe tells us how the mind can affect ghost encounters and a weird experience that even he can't explain

**88 Escape room psychology**

How unlocking the power of your mind help unlock these puzzle rooms

**92 How to think yourself smart**

How it Works explores the possibility of taking your IQ into your own hands and improving it



## MEDICINE


**102 Brain surgery**

If you thought rocket scientists had to pay attention to detail, wait until you meet this lot...

**106 Is it possible to see our thoughts?**

The brain is perhaps the most vital of the body's vital organs, yet in many ways it's also the least understood

**108 What is nitrous oxide?**

Discover the science of laughing gas

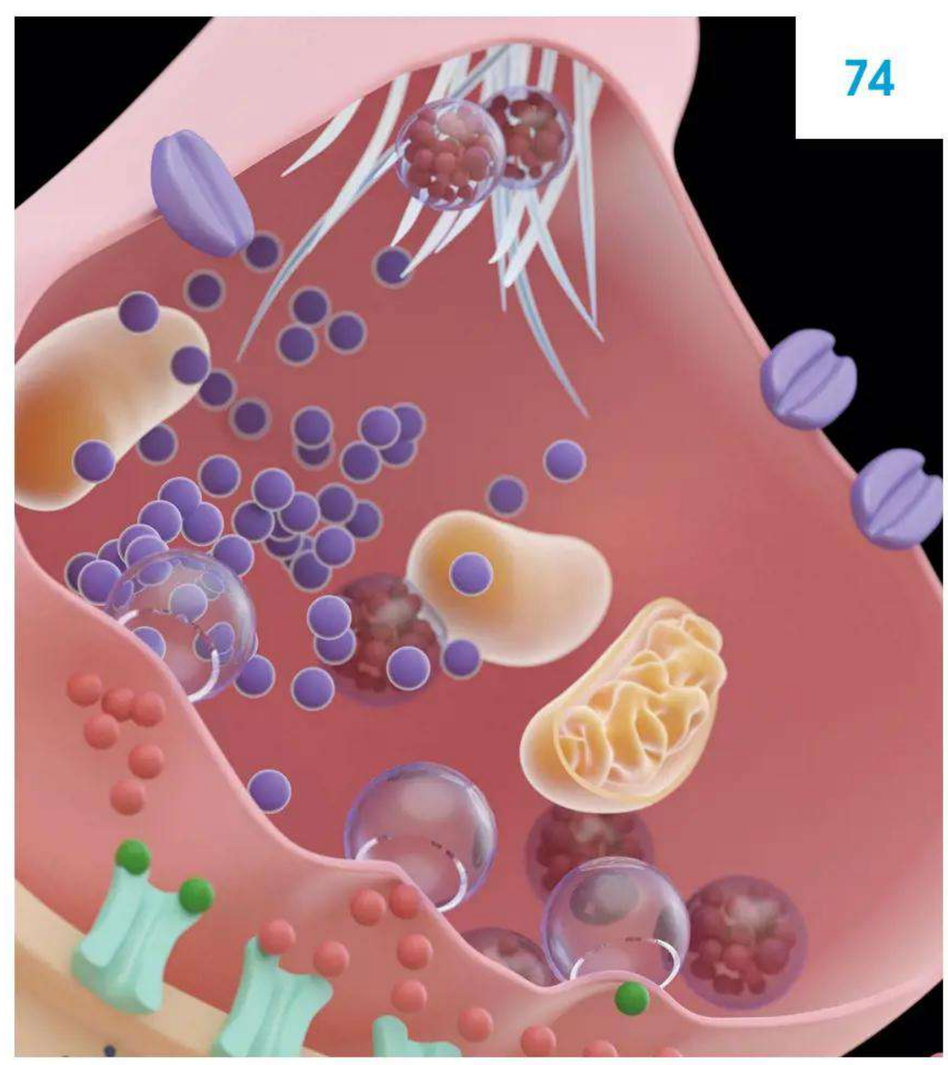

## ANIMALS

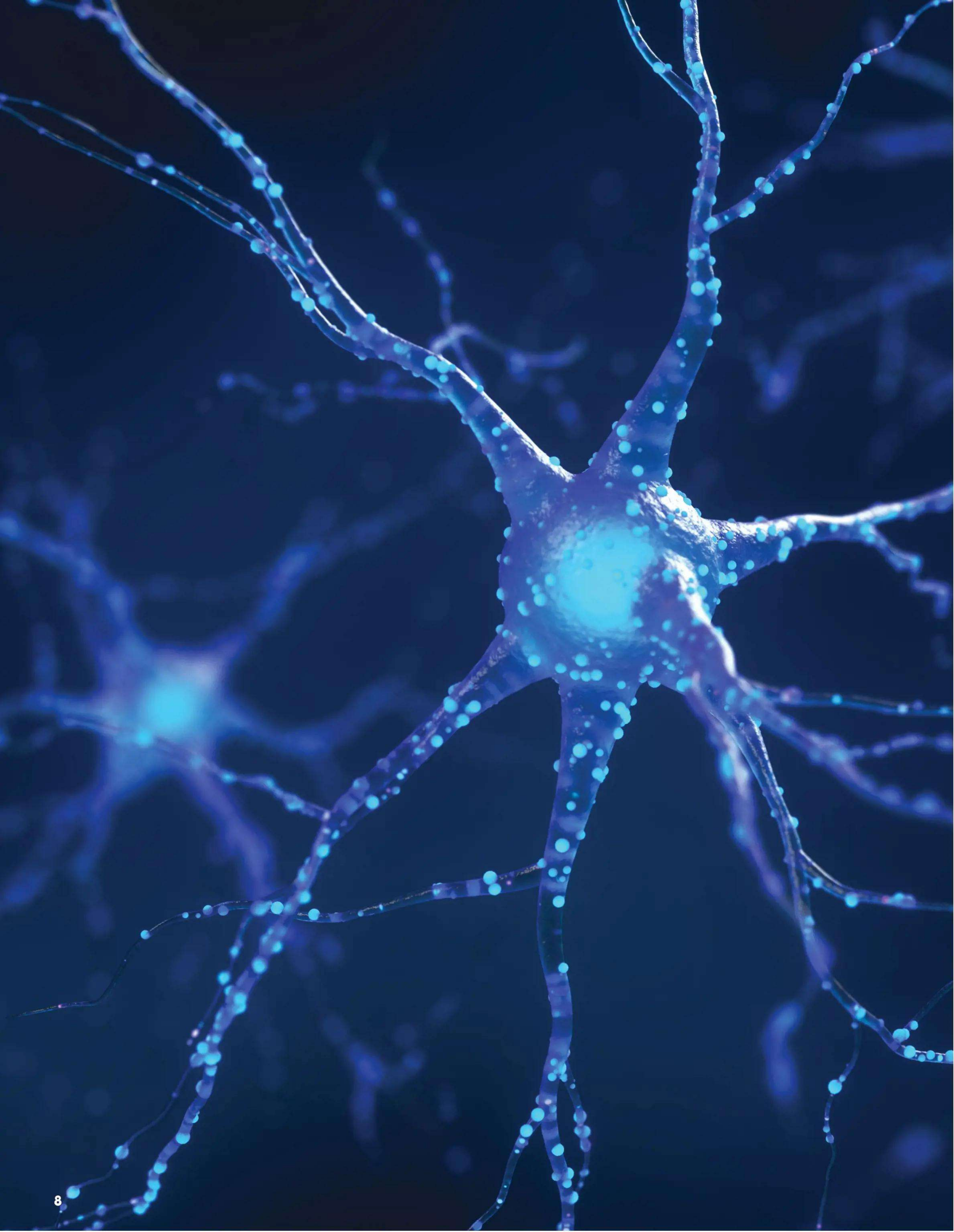

**112 How to train your pet**

Explore the brains and behaviours of different animals for better pet-human communication

**118 Are you smarter than...**

How your intelligence compares to other clever members of the animal kingdom



# Biology

# Your brain explained...

*The human brain is the most mysterious – and complex – entity in the known universe*

It's a computer, a thinking machine, a fatty pink organ, and a vast collection of neurons – but how does it actually work? The human brain is amazingly complex – in fact, more complex than anything in the known universe. The brain effortlessly consumes energy, stores your memories, processes thoughts, and lets you react to danger.

In some ways, the human brain is like a car engine. The fuel – which could be the sandwich you had for lunch or a sugar doughnut for breakfast – causes neurons to fire in a logical sequence and to bond with other neurons. This combination of neurons occurs incredibly fast, but the chain reaction might help you compose a symphony or recall entire passages of a book, help you pedal a bike or write an email to a friend.

Scientists are just beginning to understand how these brain neurons work – they have not figured out how they trigger a reaction when you touch a hot stove, for example, or why you can re-generate brain cells when you work out at the gym.

The connections inside a brain are very similar to the internet – the connections are constantly exchanging information. Yet, even the internet is rather simplistic when compared to neurons.

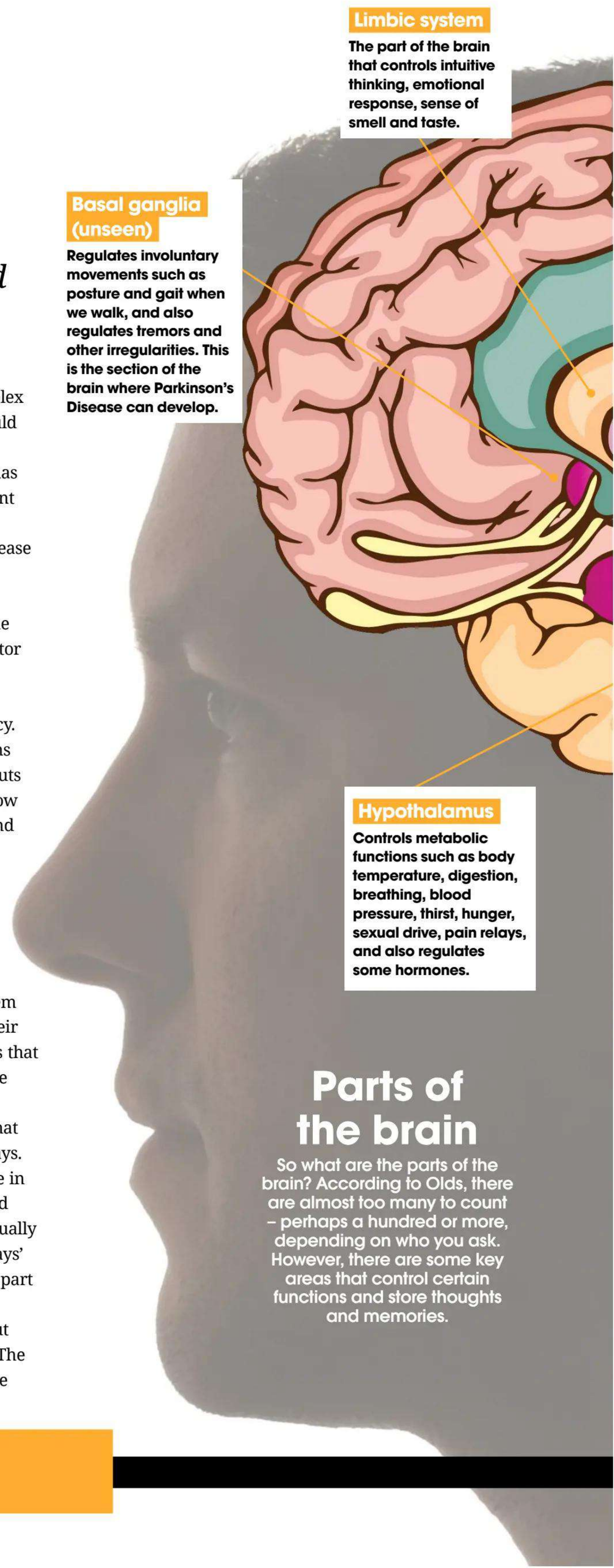
There are ten to 100 neurons, and each one makes thousands of connections. This is how the brain processes information, or determines how to move an arm and grip a surface. These calculations, perceptions, memories, and reactions occur almost instantaneously, and not just a few times per minute, but millions. According to Jim Olds, research director with George Mason University, if the internet were as complex as our solar system, then the brain would be as complex as our galaxy. In other words, we have a lot to learn. Science has not given up trying, and has made recent discoveries about how we adapt, learn new information, and can actually increase brain capability.

In the most basic sense, our brain is the centre of all input and outputs in the human body. Dr Paula Tallal, a co-director of neuroscience at Rutgers University, says the brain is constantly processing sensory information – even from infancy. "It's easiest to think of the brain in terms of inputs and outputs," says Tallal. "Inputs are sensory information, outputs are how our brain organises that information and controls our motor systems."

Tallal says one of the primary functions of the brain is in learning to predict what comes next. In her research for Scientific Learning, she has found that young children enjoy having the same book read to them again and again because that is how their developing brains register acoustic cues that form into phonemes (sounds) to become spoken words.

"We learn to put things together so that they become smooth sequences," she says. These smooth sequences are observable in the brain, interpreting the outside world and making sense of it. The brain is actually a series of interconnected 'superhighways' or pathways that move 'data' from one part of the body to another.

Tallal says another way to think about the brain is by lower and upper areas. The spinal cord moves information up to the




## Parts of the brain

So what are the parts of the brain? According to Olds, there are almost too many to count – perhaps a hundred or more, depending on who you ask. However, there are some key areas that control certain functions and store thoughts and memories.

**Cerebral cortex**

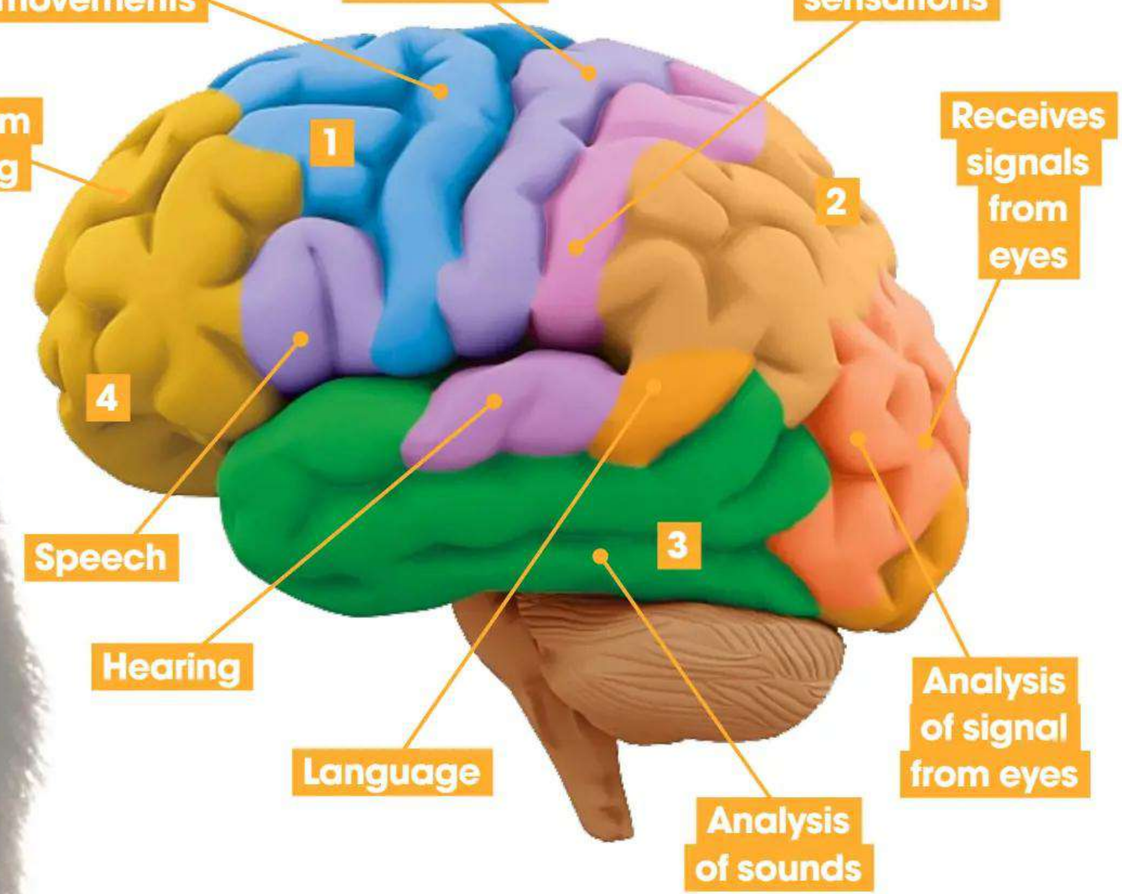
The 'grey matter' of the brain controls cognition, motor activity, sensation, and other higher level functions. Includes the association areas which help process information. These association areas are what distinguishes the human brain from other brains.

**Cerebellum**

Consists of two cerebral hemispheres that controls motor activity, the planning of movements, co-ordination, and other body functions. This section of the brain weighs about 200 grams (compared to 1,300 grams for the main cortex).

# Functions of the cerebral cortex

The cerebral cortex is the wrinkling part of our brain that shows up when you see pictures of the brain




**1 Frontal lobe**

Primarily controls senses such as taste, hearing, and smell. Association areas might help us determine language and the tone of someone's voice.

**2 Parietal lobe**

Where the brain senses touch and anything that interacts with the surface of the skin, makes us aware of the feelings of our body and where we are in space.

**3 Temporal lobe**

What distinguishes the human brain – the ability to process and interpret what other parts of the brain are hearing, sensing, or tasting and determine a response.

**4 Prefrontal cortex**

Executive functions such as complex planning, memorising, social and verbal skills, and anything that requires advanced thinking and interactions. In adults, helps us determine whether an action makes sense or is dangerous.

**"In a sense, the main function of the brain is in ordering information – interpreting the outside world and making sense of it"**

brain stem, then up into the cerebral cortex which controls thoughts and memories. Interestingly, the brain really does work like a powerful computer in determining not only movements but registering memories that can be quickly recalled.

According to Dr Robert Melillo, a neurologist and the founder of the Brain Balance Centers (www.brainbalancecenters.com), says the brain actually predetermines actions and calculates the results about a half-second before you perform them - or even faster in some cases. This means that, when you reach out to open a door, your brain has already predetermined how to move your elbow and clasp your hand – maybe it has even simulated this movement more than once, before you can even perform the action.

Another interesting aspect to the brain is that there are some voluntary movements and some involuntary. Some sections of the brain might control a voluntary movement – such as patting your knee to a beat. Another section controls involuntary movements, such as the gait of your walk – which is passed down from your parents. Reflexes, long-term memories, the pain reflex – they are all controlled by sections in the brain.

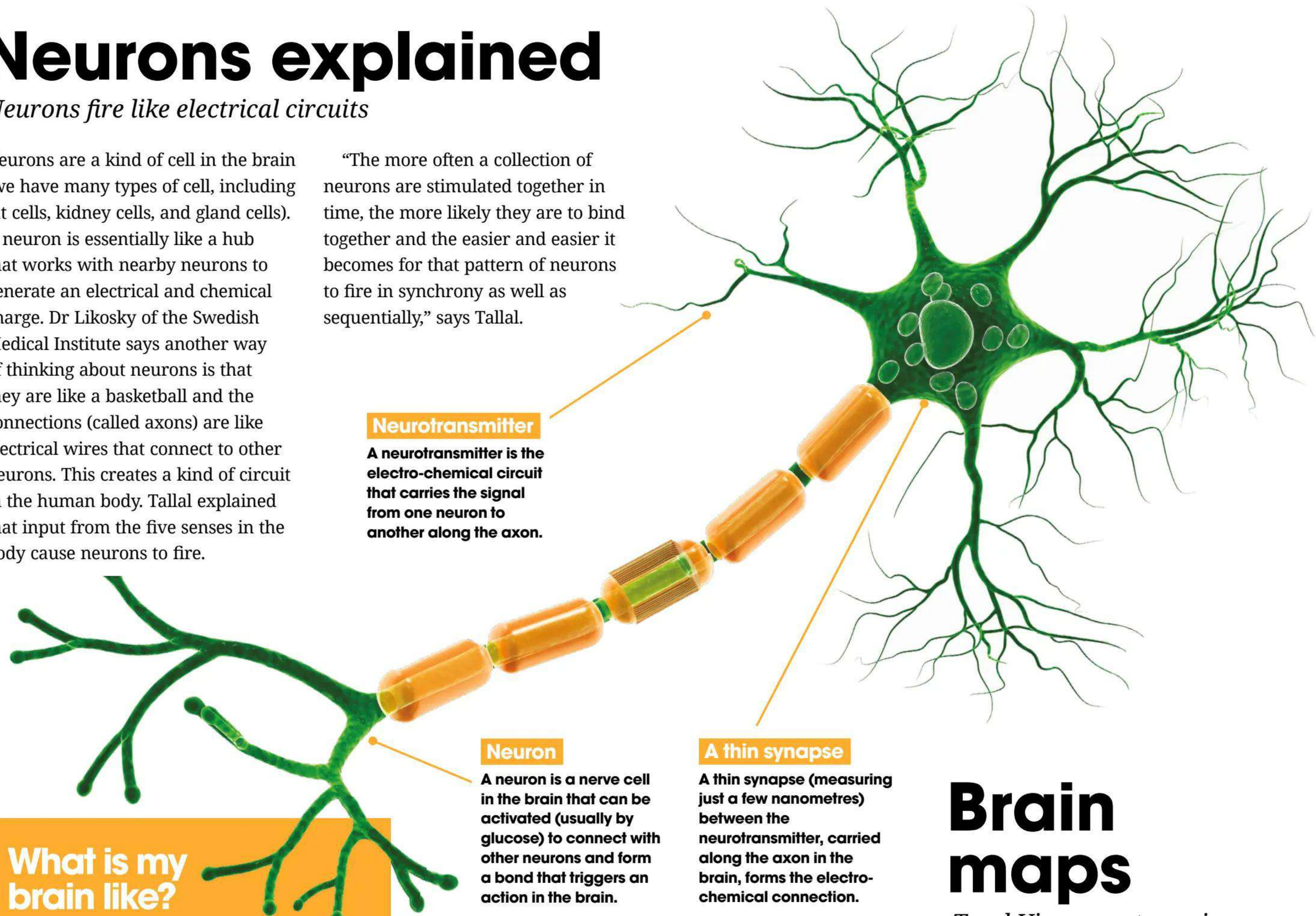
© iStock

# Neurons explained

*Neurons fire like electrical circuits*

Neurons are a kind of cell in the brain (we have many types of cell, including fat cells, kidney cells, and gland cells). A neuron is essentially like a hub that works with nearby neurons to generate an electrical and chemical charge. Dr Likosky of the Swedish Medical Institute says another way of thinking about neurons is that they are like a basketball and the connections (called axons) are like electrical wires that connect to other neurons. This creates a kind of circuit in the human body. Tallal explained that input from the five senses in the body cause neurons to fire.

"The more often a collection of neurons are stimulated together in time, the more likely they are to bind together and the easier and easier it becomes for that pattern of neurons to fire in synchrony as well as sequentially," says Tallal.



**Neurotransmitter**

**A neurotransmitter is the electro-chemical circuit that carries the signal from one neuron to another along the axon.**

**Neuron**

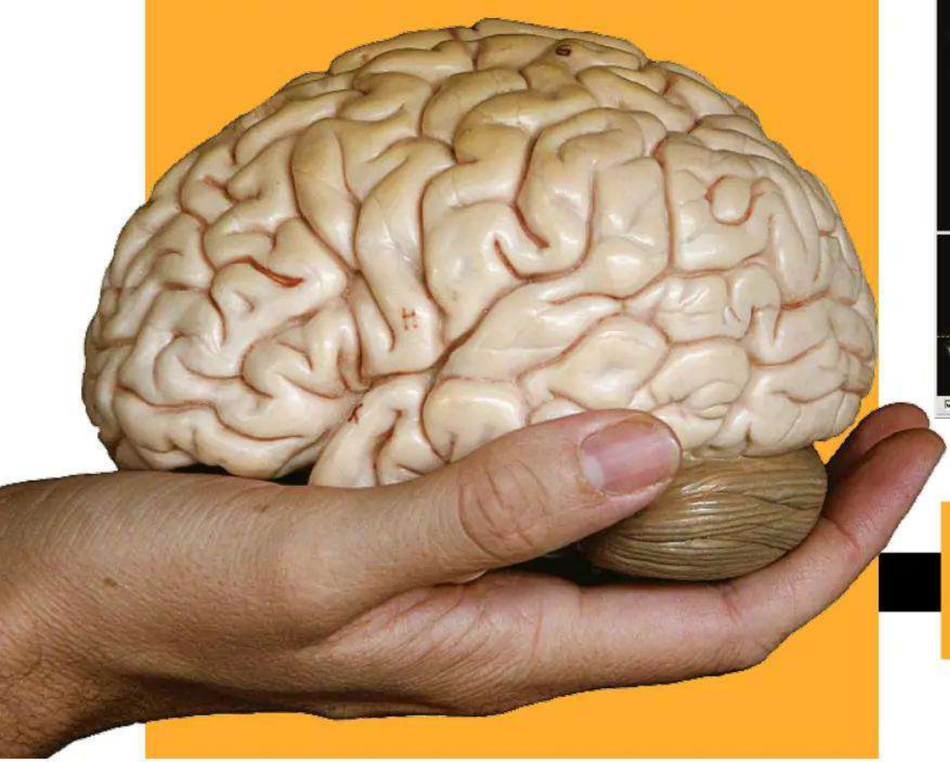
**A neuron is a nerve cell in the brain that can be activated (usually by glucose) to connect with other neurons and form a bond that triggers an action in the brain.**

**A thin synapse**

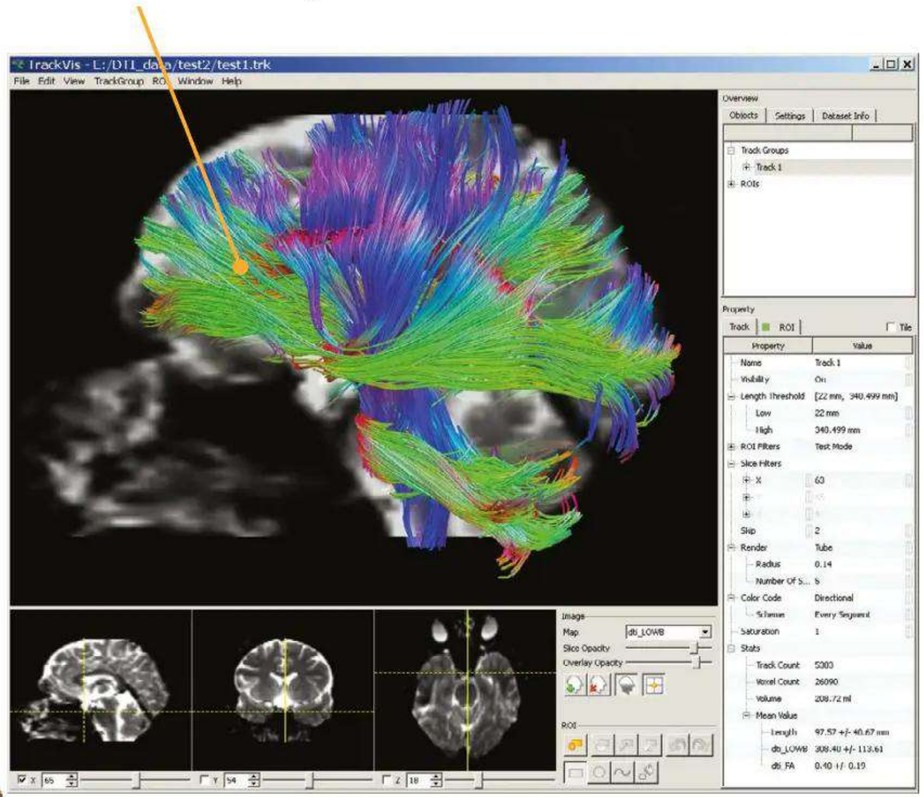
**A thin synapse (measuring just a few nanometres) between the neurotransmitter, carried along the axon in the brain, forms the electro-chemical connection.**

## What is my brain like?

In pictures, the human brain looks pink and spongy. According to Dr William Likosky, a neurologist at the Swedish Medical Institute (www.swedish.org), the brain is actually quite different from what most people think. Likosky described the brain as being not unlike feta cheese in appearance, a fragile organ that weighs about 1,500 grams and sags like a bag filled with water. In the skull, the brain is highly protected and has hard tissue, but most of the fatty tissue in the brain, which helps pass chemicals and other substances through membranes, is more delicate.



**The computers used to generate the TrackVis maps might use up to 1,000 graphics processors that work in tandem to process the data.**



# Brain maps

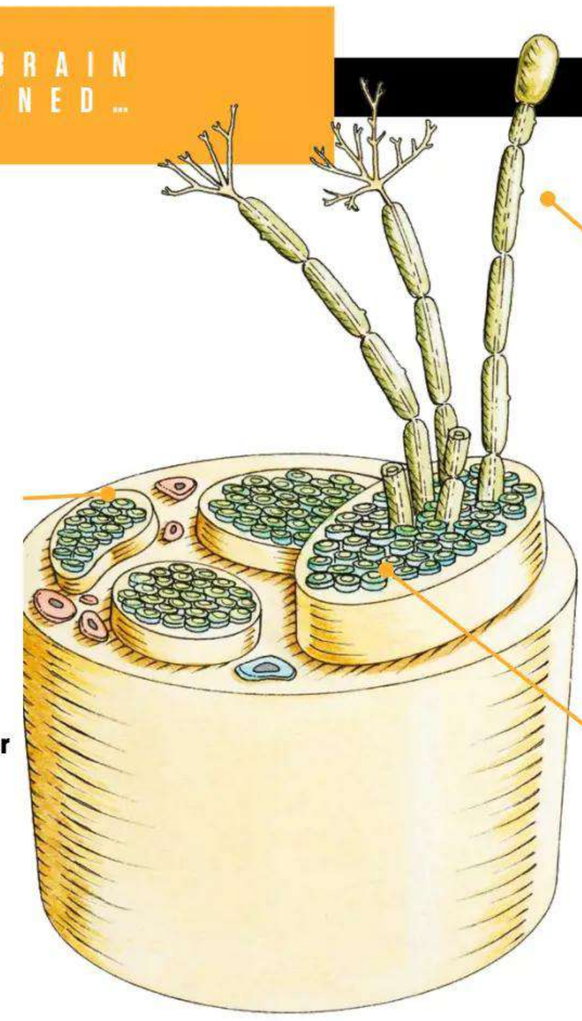
*TrackVis generates unique maps of the brain*

TrackVis is a free program used by neurologists to see a map of the brain that shows the fibre connections. On every brain, these neural pathways help connect one part of the brain to another so that a feeling you experience in one part of the brain can be transmitted and processed by another part of the brain (one that may decide the touch is harmful or pleasant). TrackVis uses fMRI readings on actual patients to generate the colourful and eye-catching images. To construct the maps, the program can take several hours to determine exactly how the fibres are positioning in the brain.

# How do nerves work?

*Nerves carry signals throughout the body – a chemical superhighway*

Nerves are the transmission cables that carry brain waves in the human body, says Sol Diamond, an assistant professor at the Thayer School of Engineering at Dartmouth. According to Diamond, nerves communicate these signals from one point to another, whether from your toenail up to your brain or from the side of your head.



**Myelinated and un-mylinated**

**Some nerves are myelinated (or insulated) with fatty tissue that appears white and forms a slower connection over a longer distance. Others are un-myelinated and are un-insulated. These nerves travel shorter distances.**

**Nerve transmissions**

**Some nerve transmissions travel great distances through the human body, others travel short distances – both use a de-polarisation to create the circuit. De-polarisation is like a wound-up spring that releases stored energy once triggered.**

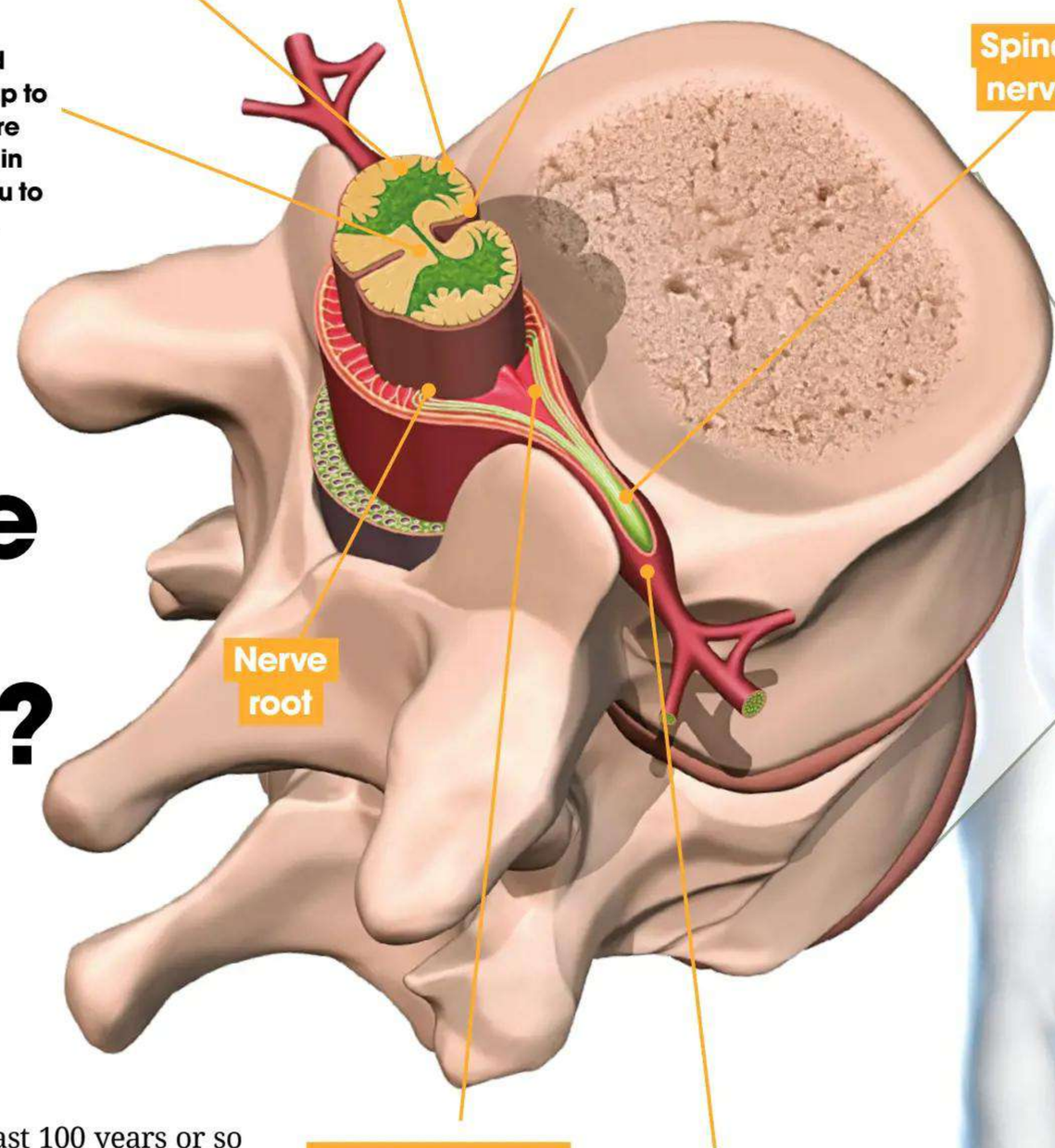
**Nerve triggers**

**When many neurons are activated together at the same time, the nerve is excited – this is when we might feel the sensation of touch or a distinct smell.**

# What does the spinal cord do?

*The spinal cord actually is part of the brain and plays a major role in the body*

Scientists have known for the past 100 years or so that the spinal cord is actually part of the brain. According to Melillo, while the brain has grey matter on the outside (protected by the skull) and protected white matter on the inside, the spinal cord is the reverse: the grey matter is inside the spinal cord and the white matter is outside.




**Grey matter cells**

**Grey matter cells in the spinal cord cannot regenerate, which is why people with a serious spinal cord injury cannot recover over time. White matter cells can re-generate.**

**White matter cells**

**White matter cells in the spinal cord carry the electro-chemical pulses up to the brain. For example, when you are kicked in the shin, you feel the pain in the shin and your brain then tells you to move your hand to cover that area.**

**Spinal cord core**

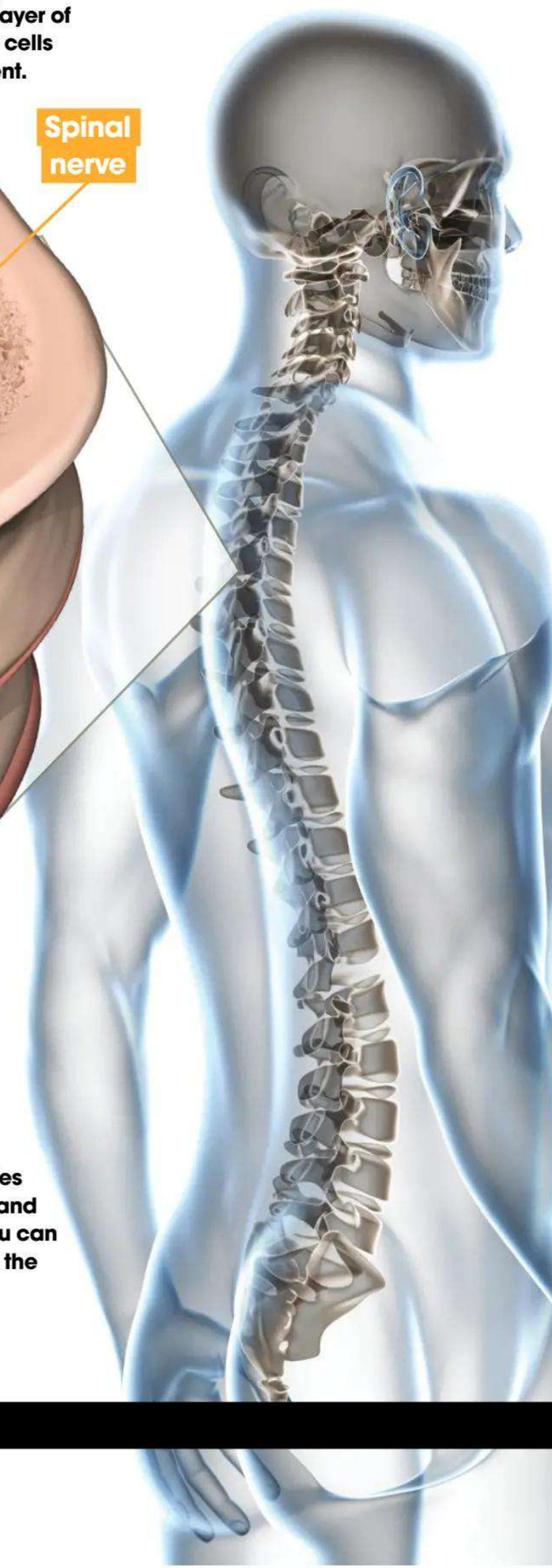
**In the core of the spinal cord, grey matter – like the kind in the outer layer of the brain – is for processing nerve cells such as touch, pain, and movement.**

**Neuroplasticity**

**In the spinal cord and in the brain, cells can rejuvenate over time when you exercise and become strengthened. This process is called neuroplasticity.**

**Neurogenesis**

**According to Tallal, by repeating brain activities such as memorisation and pattern recognition, you can grow new brain cells in the spinal cord and brain.**



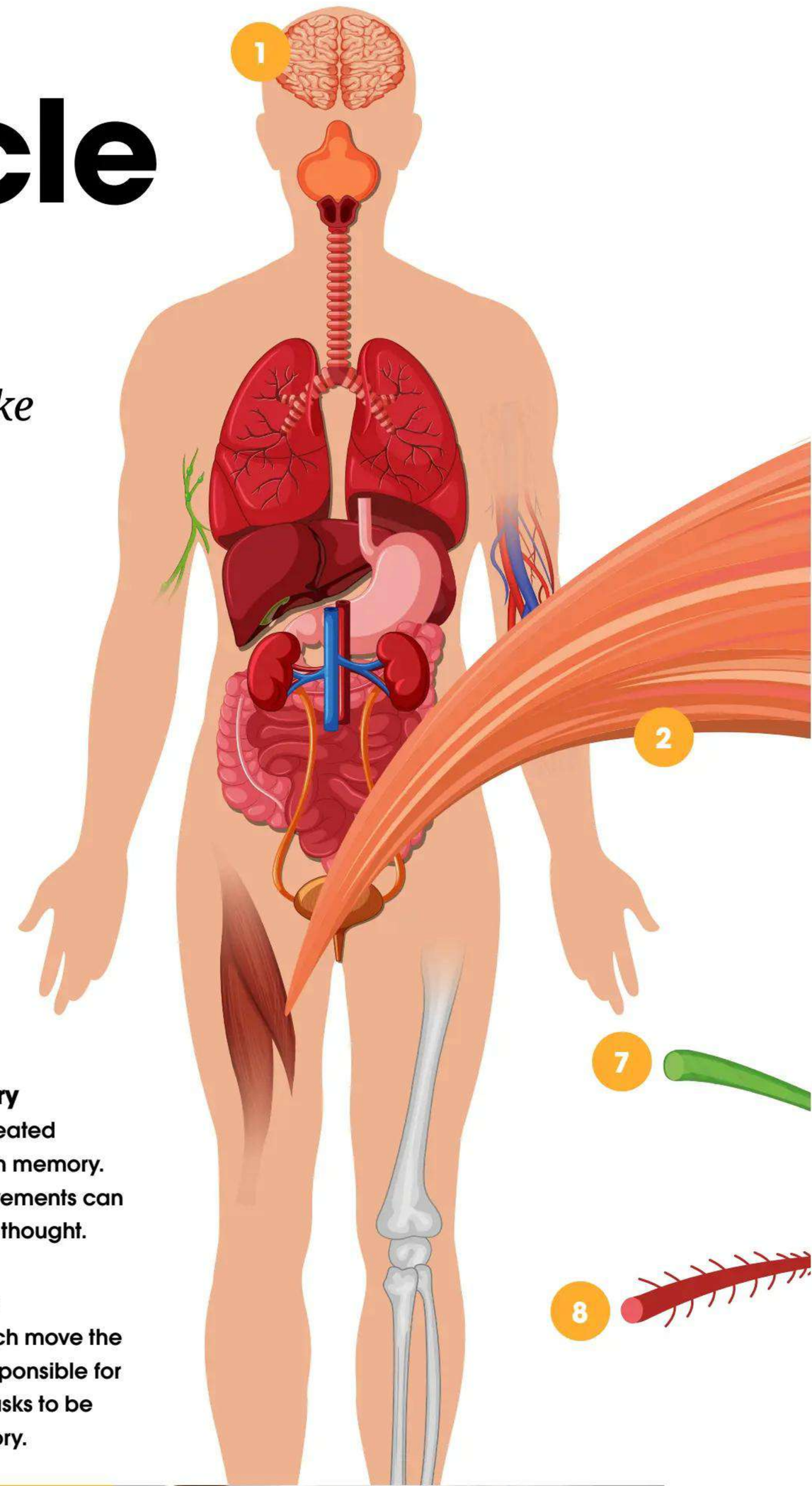
© Getty / iStock / Arrowhead Forensics

# What is muscle memory?

*How neural shortcuts in your brain make practised activities feel familiar*

When you move from one side of the room to the other, how much do you analyse the action? For most people, the series of muscle movements that allow them to get around on a daily basis is automatic. But when babies are born, their brains haven't formed the neural connection with their walking muscles in order to stand and balance. Through trial and error, they begin to master walking on two feet. Eventually, when they've discovered the movements required for walking, the neural pathways are fully formed. From this point onwards, walking becomes a natural motion that requires little conscious thought.

Have you ever learned to ride a bike, play tunes on an instrument or mastered a sport over several years? Now that you have these skills, they're unlikely to suddenly vanish. For example, you might not have ridden a bike for several years, but you'll still be able to ride one and stay in control of it with no additional lessons or guidance. Despite being called muscle memory, the body part responsible for retaining these skills is the brain. A region of the brain called the motor cortex sends signals to the muscles needed for each skill, with precise instructions to execute physical movements with accuracy. The more these signals are delivered through messenger nerve cells called neurons, the smoother each resulting action is. When these become stored in your long-term memory, skill-based memories like riding a bike are recalled as soon as you sit in the saddle.




**1 Long-term memory**
The brain stores repeated movements in long-term memory. This means muscle movements can be performed with little thought.

**2 Skeletal muscles**
These muscles, which move the body's skeleton, are responsible for performing the motor tasks to be stored as muscle memory.

## Athlete accuracy

If you observe a professional athlete in the middle of a football match or launching themselves over a high jump bar, the ease of their movements can seem incredible. These are not superpowers, but the work of perfected muscle memory. Due to their relentless training schedules, the muscles that they need to control the dribble of a ball or expertly arch themselves over obstacles in athletics are almost preprogrammed. The strong neural connections that they have made to connect their mind and the rest of their body mean that while the brain focuses on the tactics of the competition, the body can perform complex moves without much conscious thought. An additional benefit to muscle memory in professional sportspeople is that it allows them to take breaks from the sport. Even though they may lose fitness during off-season months, not long after returning to training, their muscles can bounce back to the work they were previously trained for.

High jumpers learn the Fosbury flop – a technique which involves arching the back over the bar to keep the centre of mass below it

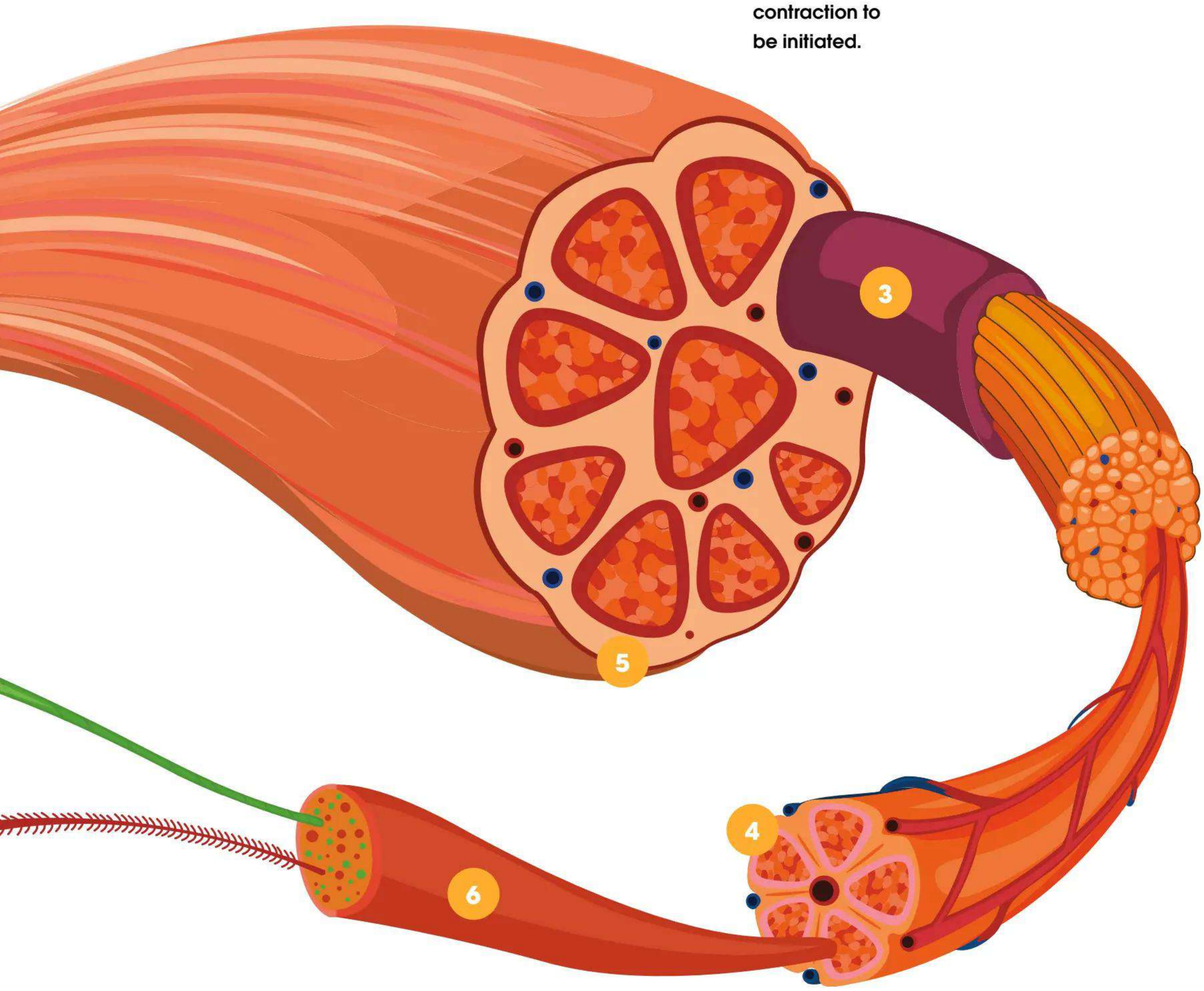
# How do muscles 'remember' movements?

The repetition of movements creates a strong connection between the muscles and brain

**3 Fasciculus**
Bundles of nerve fibre strands in the muscles connect to the central nervous system and relay signals from the brain to muscles.

**4 Sarcoplasm**
This is the water-based cytoplasm of the muscle, which is responsible for storing and releasing calcium ions. Calcium is needed for muscle contraction to be initiated.

**5 Perimysium**
This connective tissue sheath surrounds a muscle's fibre bundles and protects them from forceful muscle contractions.




**6 Muscle fibre**
The higher the number of nuclei in muscle fibres, the greater the muscle memory capacity.

**7 Myosin**
These proteins in the muscles create force that gives the muscles strength to lift, push or pull.

**8 Actin filament**
This protein filament is a mechanical component of the muscle that guides the direction of contractions as it slides along the myosin filament. After repetitive contractions, such as in weightlifting, the number of actin filaments in the muscles used increases.

## 5 muscle memory tactics to try

**1 Prioritise practice**
Practise your new sport or skill in regular and short training sessions. The more your brain is exposed to muscle patterns, the quicker it will remember and master them.

**2 Avoid bad habits**
Muscle memory can arise in any movement. Make sure you don't pick up bad habits or your brain will hold onto these and you will naturally use these techniques.

**3 Skill breakdown**
Different skills can involve a series of complex movements. Focus on each element of the movement first to make them easier to combine correctly.

**4 Switch up the environment**
When training in the same place or environment, you can limit your muscle memory. To make sure your muscles are firing correctly in different scenarios, don't make every practice session identical.

**5 Take your time**
Nobody becomes an expert overnight. Muscle memory relies on consistency and long-term repetition.

People say that you never forget how to ride a bike

© Getty / Alamy

# Unravelling the nervous system

*Explore the electrically charged network composed of billions of cells that coordinates your thoughts, feelings and actions from head to toe*

Human beings are wonderfully complex. Relative to the numerous single-celled organisms on our planet, humans are gargantuan superstructures. We boast trillions of cells that work to assemble and maintain an array of specialised tissues, organs and bones. Together these form a single being that walks, talks, thinks and feels. This exceptional complexity is only made possible by a coordination centre that monitors and controls the actions of our human form. We refer to this coordination centre as the nervous system. Consisting of the brain, spinal cord and reams of nerves that connect them to the rest of the body, the nervous system is a truly vast and dense network of cells. Collectively, their function is to exchange and relay information through electrical impulses, giving us the power of thought and action.

Many prominent thinkers of Hellenic antiquity, the ancient civilisations around Greece, were obsessed with the complexities of human thought, constantly questioning and probing our understanding of ourselves and our place in the natural world. But some scholars, such as the Greek anatomist Galen, took a literal interest in our thoughts as well as a philosophical one, and decided to delve into dissected pigs in search of the organ that made thought possible. Through his studies, Galen collected evidence that centred the brain as the hub of thought, action and memory. As well as championing the brain as the nexus of the body, Galen also found nerve fibres in his pig subjects that spread outwards from the brain and into the periphery of their bodies. He even went as far to decipher that these nerves were not all the same, but specialised into sensory nerves that received signals and motor nerves that relayed instructions.

Many years later, but not too far away, Renaissance anatomists in Italy sliced and diced human brains to expand our knowledge of the organ. They discovered specialised regions like the pons, which acts as a 'bridge' connecting other brain regions, and the hypothalamus, which was found later to control hormone production. In England in the following century, Thomas Willis deduced that the brain controlled both voluntary and involuntary actions. Scholars were beginning to map the network of the nervous system, but how signals travelled around the network only became clear once Benjamin Franklin went out in a thunderstorm holding a metal key and a kite. In doing so, he performed an experiment that led to the discovery of electricity. This allowed scientists to reconsider how our nerves receive and exchange signals, eventually inspiring Emil du Bois-Reymond to confirm that electricity is the conduit by which information is exchanged in our neural pathways.

Centuries of research uncovered the highway of cells travelled by electrical signals to govern our actions, but chemical signals are required too. Neurons don't touch one another like a continuous road, but are separated by small gaps of water containing charged atoms, or ions. These gaps are known as synapses, which act as a bridge between neurons. Once a signal reaches the end of a neuron, at the axon, compounds called neurotransmitters are released. These cross the bridge and bind to the dendrites – the signal receivers of neighbouring neurons. This causes the next neuron to 'fire' its own electrical signal.

Despite this crossing happening between every neuron, the remarkable structure of the nervous system allows signals to be sent across the body in a fraction of a second. While we now understand much about the broader organisation of nerves and the way they function on a single-cell level, the nervous system continues to hold many mysteries for us to solve.

© Getty

# Divisions of the nervous system

*Learn the hierarchies of nerve structures that keep our bodies running and safe from harm*

The brain is a hive of neuronal activity, with billions of interwoven neurons firing to preserve and recall memories, coordinate thoughts and speech and plan future actions. Along with the spinal cord, the bone-clad parts of our nervous system are called the central nervous system. The majority of our neurons are shielded behind protective fluid and bone, where they receive signals from and dictate to organs around the body. However, the signals sent from the central nervous system must have some means of reaching their target organs. For that they need to connect to nerves that stretch from the central nervous system all the way to the extremities of the body. This second network of nerves is called the peripheral nervous system. Together the central and peripheral form the major divisions of the nervous system.

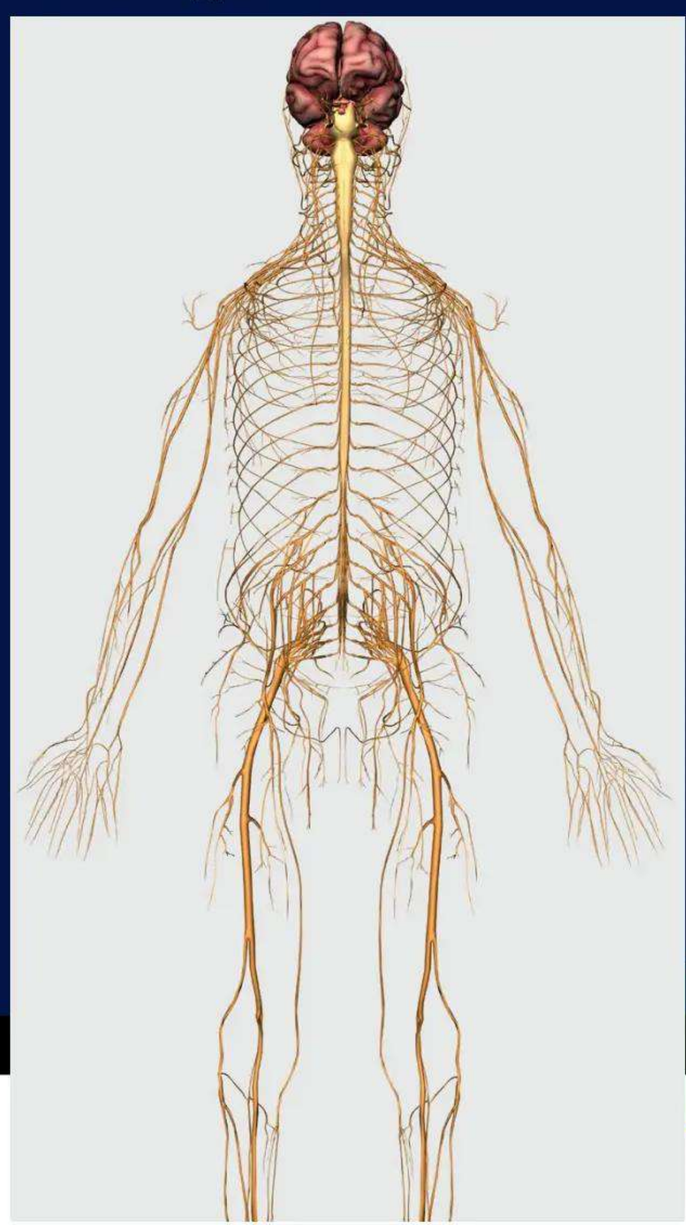
The peripheral nervous system is responsible for many functions, and as such has numerous subdivisions that specialise in different tasks. The sensory, or afferent division receives signals from the periphery and carries these into the central nervous system. The motor, or efferent division transmits signals for actions outwards from the central nervous system to the peripheral organs and muscles. These motor functions come in two forms: somatic and autonomic. Somatic functions are perhaps the easiest concept of the nervous system to grasp, as these dictate all of our voluntary actions, such as choosing to pick up a cup or jump on the bed.

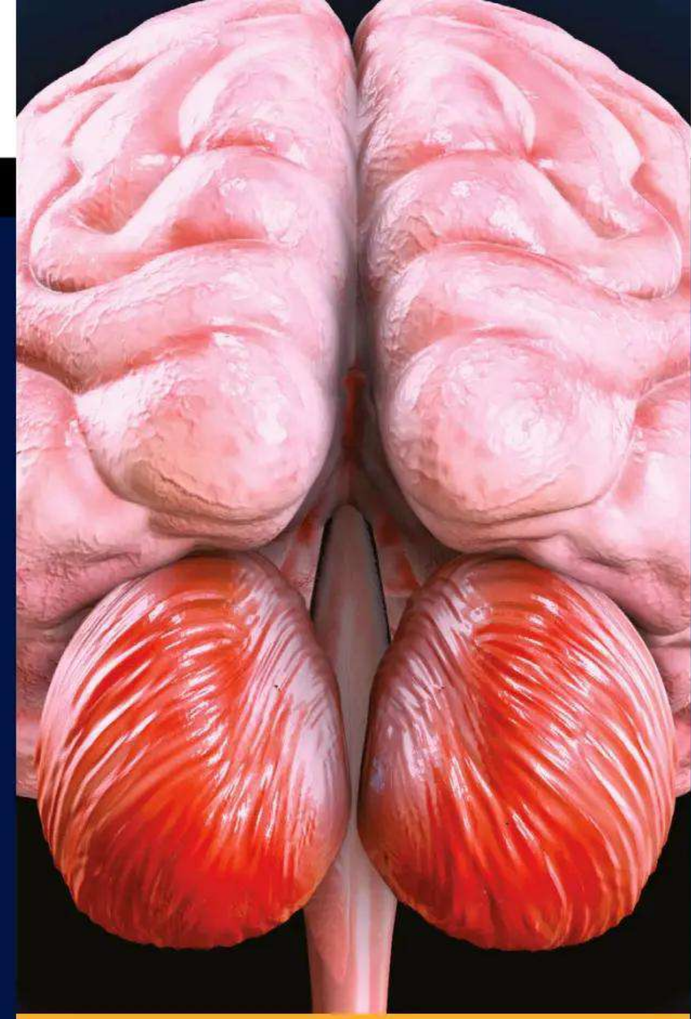
Not all somatic motor functions are voluntary. Some are automatic, preprogrammed responses built into our bodies that help us cope with danger, known as somatic reflexes. You'll notice such a reflex when you accidentally touch a hot stove, step on a sharp object or something flies towards your eye – your body reacts before you're aware of it. Your hand pulls away, you hop onto the other foot or your eyelid slams shut. This is all the work of somatic reflexes, which can act incredibly quickly as they do not require voluntary input from the brain. Such reflexes can come in different flavours – pulling your hand away from danger is known as a flexor or withdrawal reflex, whereas stepping on a sharp object initiates a crossed-extensor reflex. This latter reflex automatically triggers multiple motor functions: as one leg retracts the other leg simultaneously expands and becomes more stable, preventing us from falling over.

The innate, hard-wired reflex responses of our peripheral nervous system help keep us safe from danger, but they are not the only automatic functions performed by the peripheral nervous system. When actions are not somatic, they are autonomic, which means they operate independently of conscious thought. Such processes include your heartbeat, the churning of food in the digestive tract and respiration. While our brain can assume control of a few of these processes, like holding your breath, autonomic functions will operate even when we fall asleep or are unconscious.

The processes that we cannot control, however, aren't unchanging. The organs under the control of the autonomic nervous system are regulated by a balance between the sympathetic and parasympathetic nervous systems. Depending on stimuli, these systems increase or decrease activity of our internal organs, helping to ensure our body is always ready to respond to the challenge at hand.

Unlike many peripheral nerves, the nerves of the central nervous system are surrounded by protective bone





The brain is composed of three major regions; the cerebrum is the largest

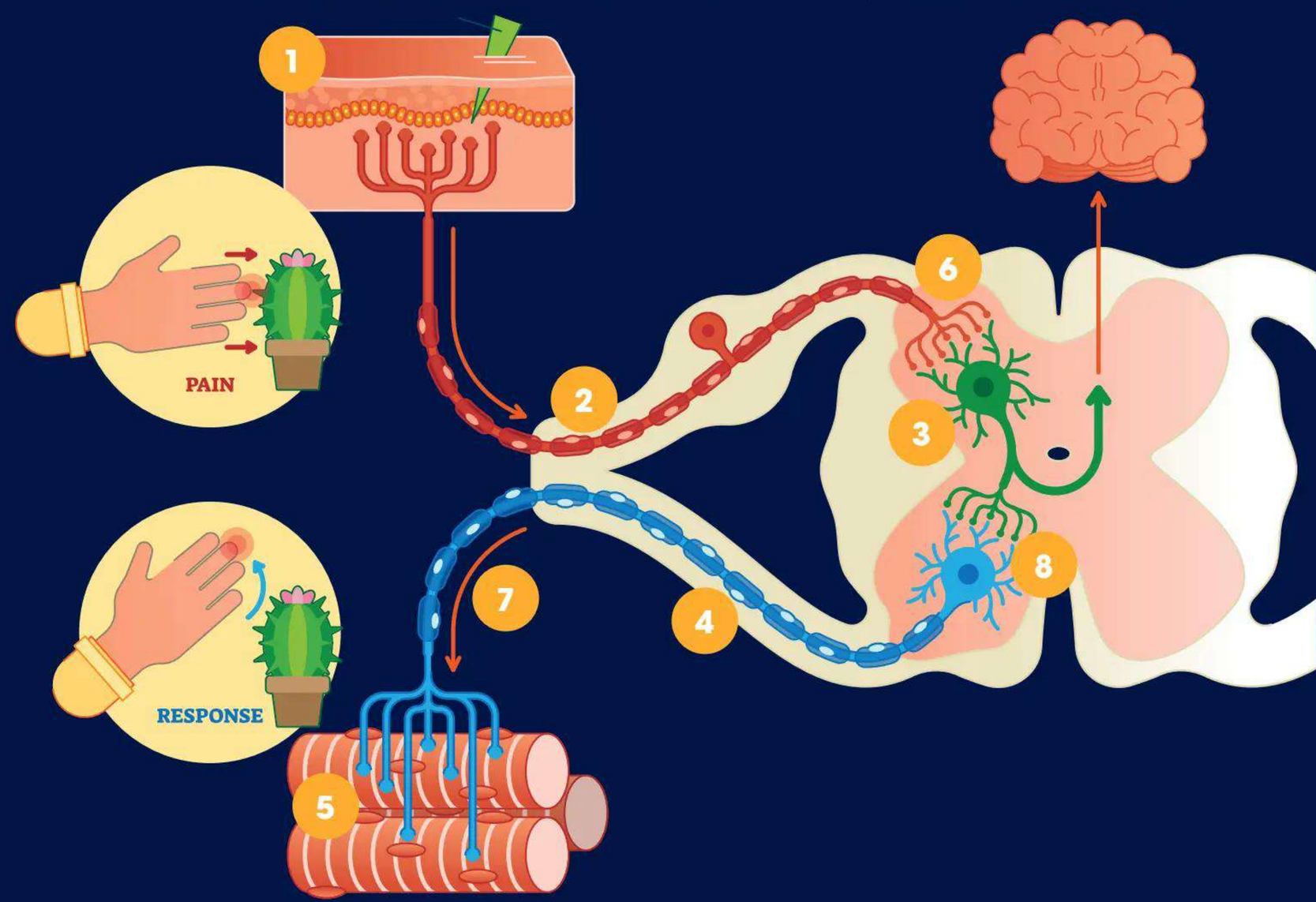
## Regions of the brain

The brain makes sense of the world around us. It collects information from the five senses, interprets them and returns with instructions for the body's muscles and organs using its three major domains. The cerebrum is the largest part of the brain. It's split into two hemispheres, separated by a fissure that's visible when looking at the brain from above. The left hemisphere controls muscles on the right side of the body, and vice versa.

As well as motor control, the cerebrum is responsible for interpreting touch, vision and sound; controlling our sense of reasoning and determining our emotions. The cerebellum, nestled under the cerebrum, coordinates posture, balance and other muscle movements. Finally, the brainstem acts as a conduit, connecting the other regions of the brain to the spinal cord.

# The reflex arc

Your nervous system rescues you from imminent harm using hard-wired reflex actions




**1 Detection**
When your cells are at risk, such as when you accidentally touch a hot stove, receptors in your skin initiate a nerve impulse.

**2 Sensor neuron**
The nerve impulse travels from the dendrites of the sensory neuron towards the spinal cord.

**3 Interneuron**
Located in the spinal cord, the interneuron acts as a relay between the sensor and motor neurons, passing the impulse onto the latter.

**4 Motor neuron**
The nerve impulse travels away from the spinal cord and towards the target muscle receptors via the motor neuron.

**5 Motor function**
The signal forces muscles to contract, pulling your hand away from the heat source automatically without any conscious thought needed.

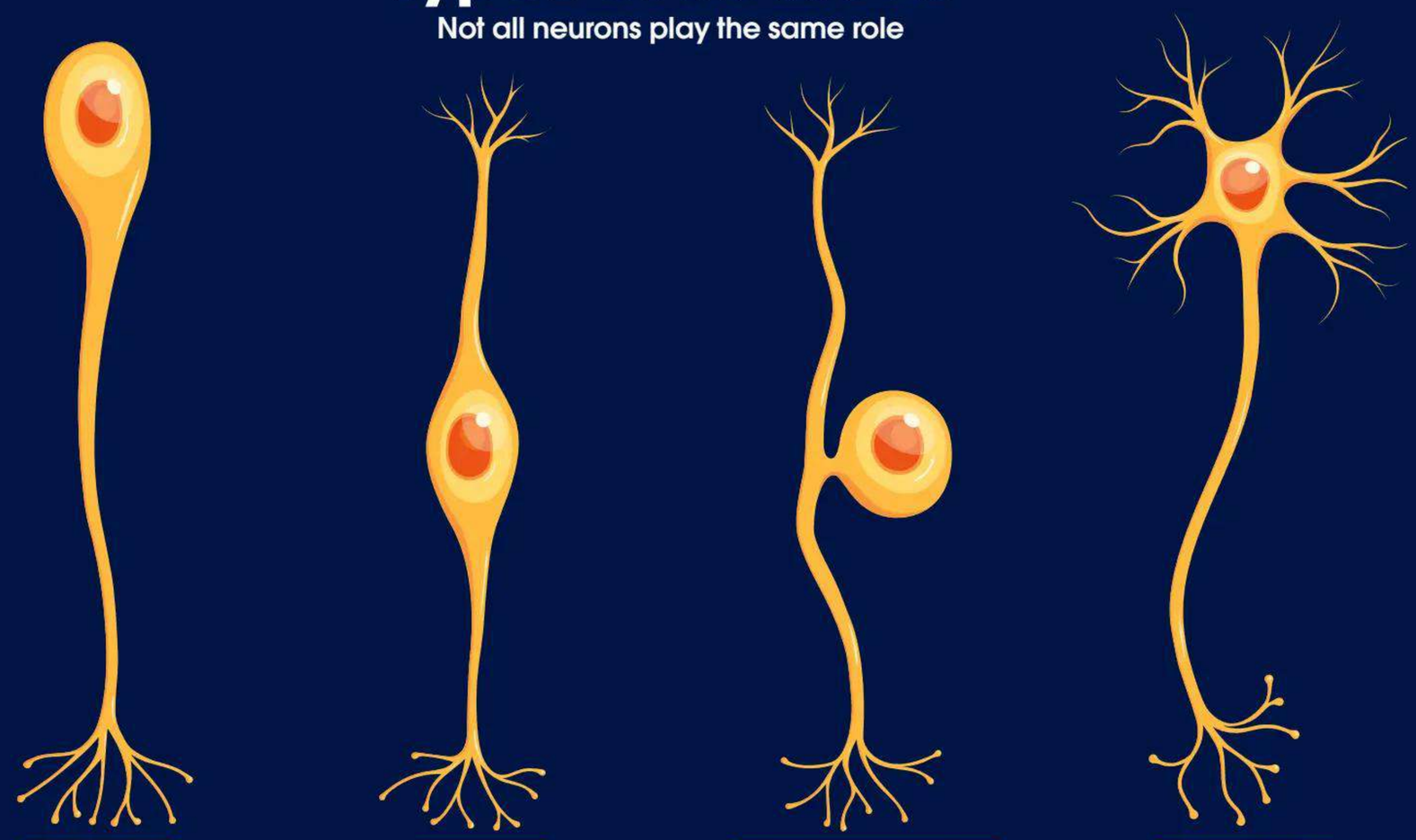
**6 Close neighbours**
The nerve impulse reaches connected neurons by 'jumping' across the synapse, a small gap that lies between them.

**7 One-way traffic**
The nerve impulse travels in one direction, starting at the sensory neuron and terminating at the end of the motor neuron.

**8 Polysynaptic reflex**
Reflexes can trigger either simple or complex responses. Polysynaptic reflexes can send signals to many muscles, allowing us to simultaneously contract them during a reflex.

# Types of neurons

Not all neurons play the same role



**Unipolar**
A useful way of defining neurons is by the number of processes, or branches, that extend from the cell body. A unipolar neuron has just one axon branch.

**Bipolar**
These neurons have one dendrite and one axon extending in opposite directions. They are found up your nose and behind your eyes.

**Psuedounipolar**
These have one branch that extends from the cell body and splits into two branches. These neurons help connect the peripheral to the central nervous system.

**Multipolar**
Our most common type of neuron, which is numerous in the central nervous system. These possess many dendrites and a single axon.

© Getty

# Relaxing or taxing

*How we feel can affect our body in many ways*

## Sympathetic nervous system

When we feel threatened, our instinctual reaction is known as the fight-or-flight stress response. The response induces a suite of physiological actions to help us cope with the challenge.

**Dilated pupils**
Adrenaline causes the pupils to widen, allowing the eyes to absorb more information from their surroundings.

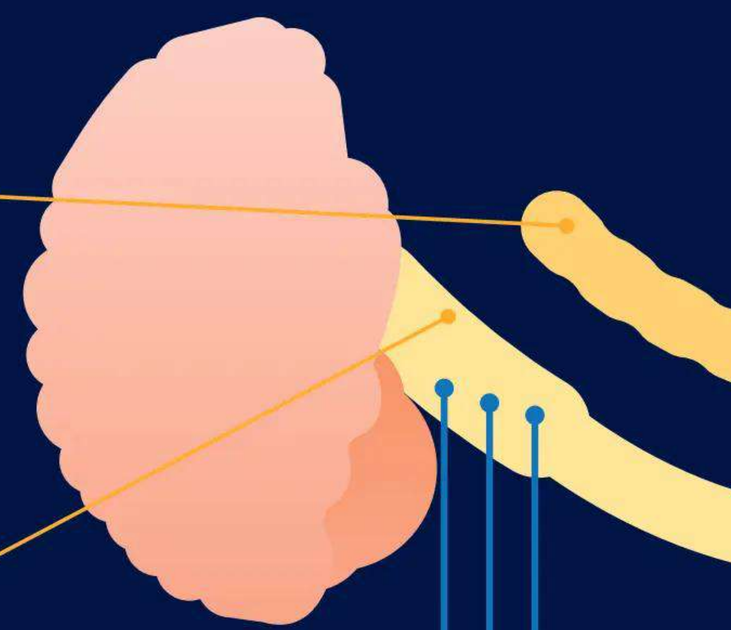
**Inhibited salivary glands**
Increased noradrenaline depresses the activity of saliva-producing acinar cells, helping to slow the digestive tract.

**Expanded airways**
Adrenaline expands the airways lining the lungs, allowing the increased blood supply to more readily oxygenate.

**Increased heart rate**
The heartbeat quickens following exposure to adrenaline. This improves the blood supply to muscles and the brain.

**Spinal connections**
Organs connect to the sympathetic nerves via distinct ganglia that emerge from different regions of the spine.

**Acetylcholine**
Much of the parasympathetic nervous system involves muscarinic receptors, which are activated by the molecule acetylcholine.



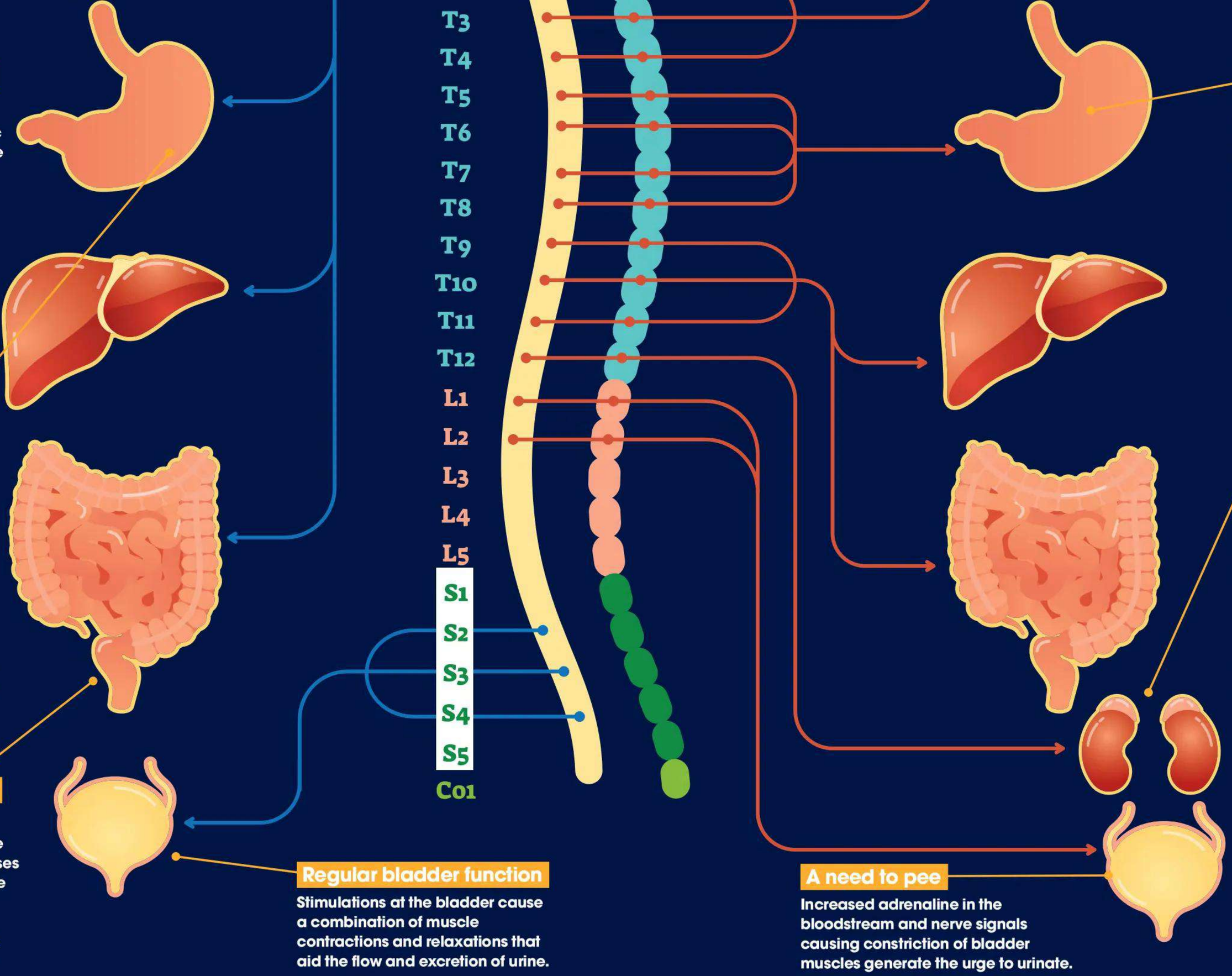
## Parasympathetic nervous system

When we're free from periods of stress, our body responds by reverting to a more balanced state of rest and digest.

**Pupil constriction**
Stimulated muscarinic receptors in the eye cause contraction of the iris' sphincter muscle and the ciliary muscle, improving near vision.

**Stimulated saliva secretion**
Parasympathetic stimulation causes the secretion of saliva components, including water, amylase and potassium ions.

**Constricted airways**
The large tubes of the lungs, known as bronchi, constrict and stimulate secretions. These processes help protect the lungs from airborne irritants.




**Decreased heart rate**

Parasympathetic inputs reduce the velocity of electrical conduction through the atrioventricular node of the heart, helping to slow contractions and reduce heart rate.

**Increased digestion**

Muscarinic receptor stimulation increases secretions of gastric juices and relaxes sphincters, helping digested matter to move through the digestive tract.

**Increased gallbladder activity**

Stimulation at the gallbladder causes contraction of the organ and the release of bile, which aids in the digestion of fats.

**Regular bladder function**

Stimulations at the bladder cause a combination of muscle contractions and relaxations that aid the flow and excretion of urine.

**Inhibited digestive activity**

Nerve signals from the celiac ganglion suppress production of gastric acid and bile and reduce muscle contractions that churn food in the stomach and intestines.

**Secretion of stress hormones**

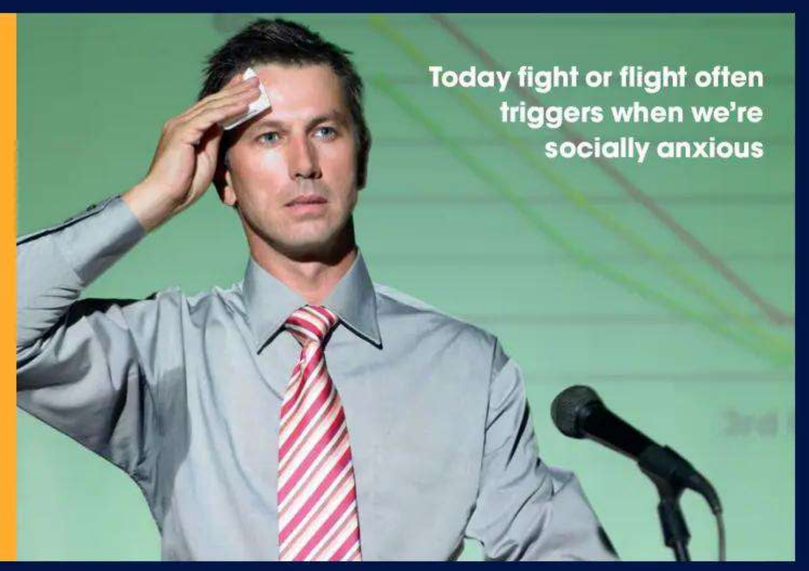
Autonomic nerves trigger the adrenal glands to release adrenaline, noradrenaline, and cortisol. These hormones will subsequently initiate other physiological effects throughout the body.

**A need to pee**

Increased adrenaline in the bloodstream and nerve signals causing constriction of bladder muscles generate the urge to urinate.

## A bear or a boss?

The fight-or-flight sympathetic stress response evolved to help humans survive encounters with predators. For much of our hunter-gatherer existence, as we explored the wilderness, discovered new environments and spread across the globe, we encountered all manner of dangerous fauna. For some of these encounters, quick reaction times would have been vital, helping those with an attuned response survive and pass on their genes to the next generation. Today most of us have little to fear from a hungry panther or a territorial grizzly bear, but the stress response is still routinely triggered, just by other means. Now many of us encounter the same intrinsic response when we run into an angry teacher in the corridor or when we have to present unexpectedly to our employer's CEO at the annual meeting.



Today fight or flight often triggers when we're socially anxious

© Getty

# Diseases and Damage

*As the connective network coordinating our body, damage to the nervous system can be debilitating*

Spinal surgery can be used to treat herniated discs by alleviating pressure on the spinal cord

## 5 ways cortisol affects us

**1 All over**
Cortisol is the main stress-response agent in the body. Adrenaline and noradrenaline affect multiple organs, but cortisol is ubiquitous – most cells in the body possess cortisol receptors

**2 Sounding the alarm**
The hypothalamus is a small region of the brain that monitors and regulates the stress response. During periods of stress, the hypothalamus signals the pea-sized pituitary gland to stimulate cortisol release.

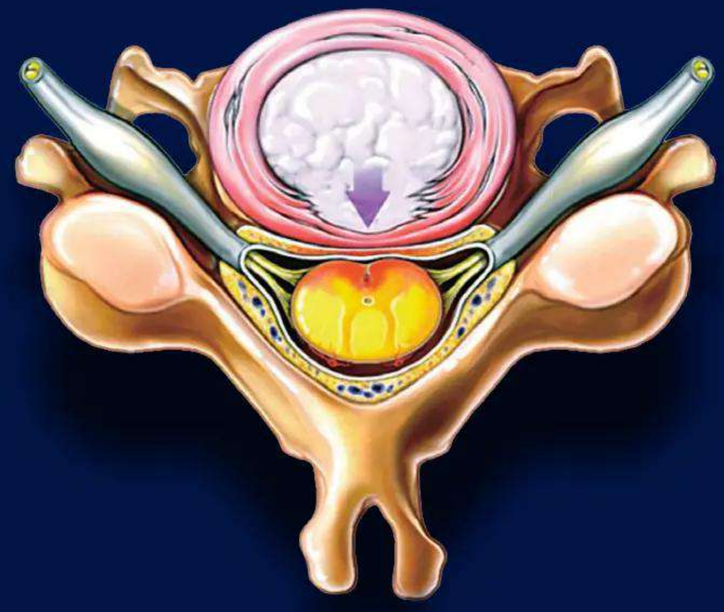
**3 Give me fuel**
During the fight-or-flight response the body may need to act quickly, and for that it needs energy. Cortisol provides this fuel by stimulating the release of glucose.

**4 Priorities**
Non-vital organs for survival during periods of stress, such as the reproductive organs and immune system, are suppressed by cortisol, ensuring energy goes where it's needed most.

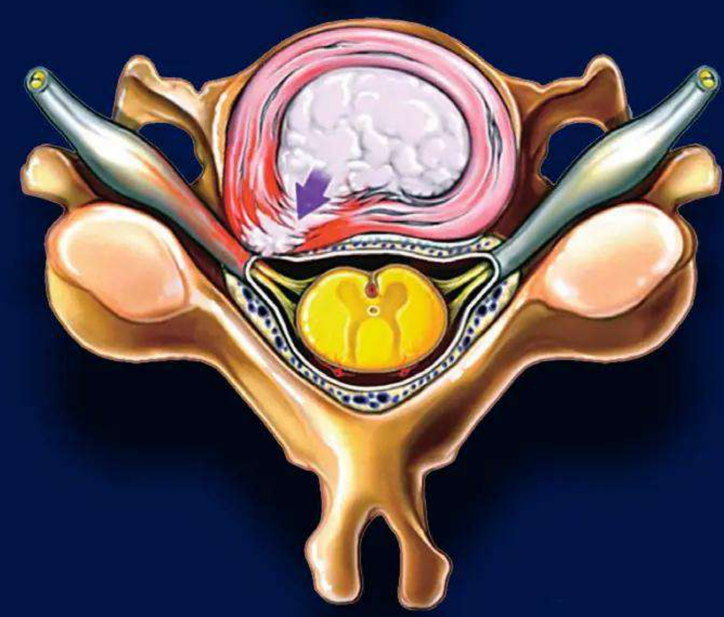
**5 Overstressed**
Cortisol aids during periods of stress and during daily function, but chronic stress overstimulates cortisol release. This risks a multitude of health problems, including anxiety and heart disease.

## Pinched nerve

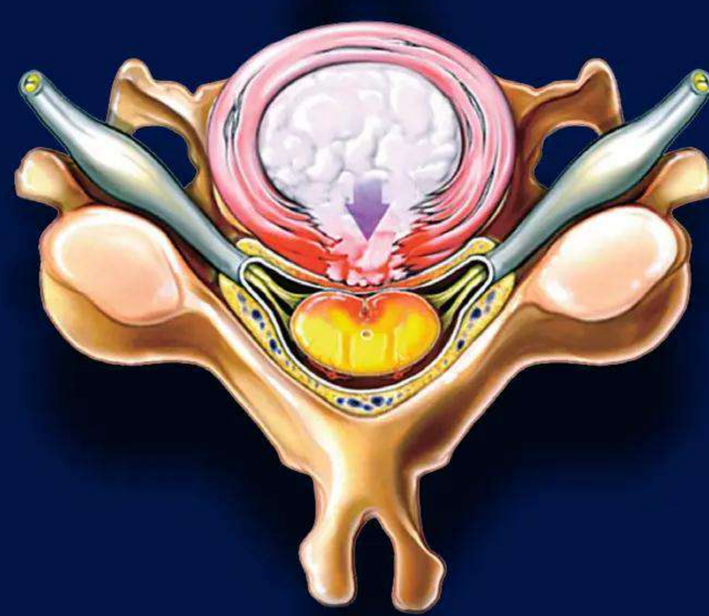
Excessive pressure from nearby tissue, including spinal discs, can 'pinch' nerves and interfere with their signalling. This results in pain, tingles, weakness or numbness as the nerve misfires



**Disc bulge**
Spinal discs rest between the vertebrae of the spine, where they act as shock absorbers. They are formed of a softer centre and tougher outer band. As we age, cartilage in the disc dries and stiffens and the outer layer bulges.



**Lateral disc herniation**
When the outer layer of the spinal disc ruptures, it's known as a herniation, which allows the softer centre of the disc to ooze out. In laterally herniated discs, this places pressure on the nerve root of the spinal cord.

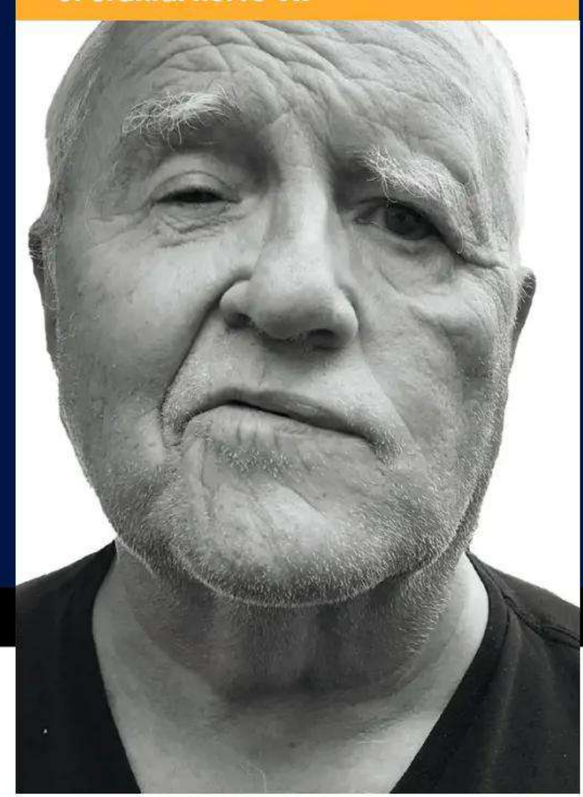


**Central disc herniation**
Central herniation can place excessive pressure on the spinal cord, causing severe compression in some cases. This can result in loss of motor function of the legs, affecting balance and strength when standing and walking.

## Bell's Palsy

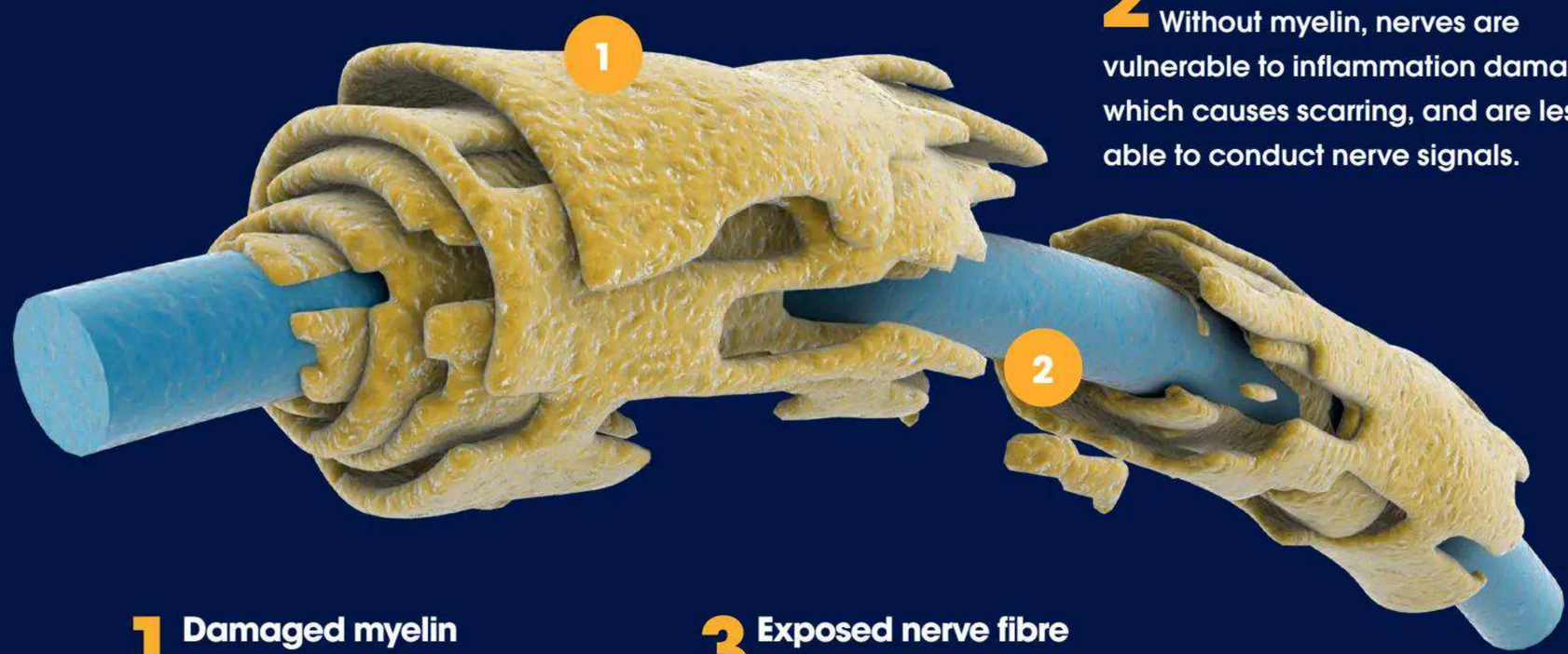
Nerves spread out from the central nervous system to various organs and tissues, with each powering specific functions. Cranial nerve VII is known as the facial nerve, as it controls many of the muscles on our face, including blinking and smiling. When this nerve is inflamed, damaged or disrupted, Bell's palsy can occur, with the facial muscles becoming weakened or paralysed. This typically affects only one side of the face, causing drooping of the mouth on one side and a loss of control of an eyelid, giving the affected side a slack appearance. The full symptoms of Bell's palsy are often temporary, with some or total recovery of the affected areas occurring within six months. While it's not always clear what causes the cranial nerve to swell and Bell's palsy to occur, scientists believe that a recurring viral infection of the nervous system elicits an immune response that triggers the nerve damage.

Bell's palsy causes paralysis in part of the face due to swelling of cranial nerve VII



# Multiple sclerosis

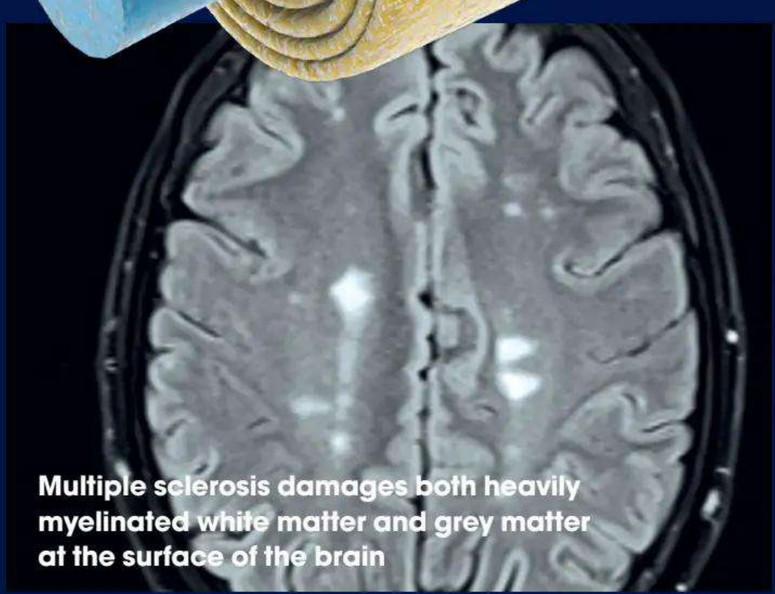
Neurons are the agents of signalling in our bodies, but they don't work alone. Axons, which carry signals away from the neuron's cell body, are coated in a sheaf of myelin. Myelin sheaves are produced in the central nervous system by cells called oligodendrocytes, enabling myelin's function of protecting and facilitating nerve conductivity. In multiple sclerosis, an abnormal immune response strips away the protective myelin and causes lots of nerve scarring, or sclerosis, which gives the disease its name. Research efforts are underway to treat the disease by encouraging myelin regeneration.




**2 Exposed nerve fibre**
Without myelin, nerves are vulnerable to inflammation damage, which causes scarring, and are less able to conduct nerve signals.

**1 Damaged myelin**
In multiple sclerosis, the immune system causes inflammation that destroys myelin and the cells that produce it.

**3 Exposed nerve fibre**
Without myelin, nerves are vulnerable to inflammation damage, which causes scarring, and are less able to conduct nerve signals.



Multiple sclerosis damages both heavily myelinated white matter and grey matter at the surface of the brain

Research is in progress to use virtual reality as a diagnostic tool for neurological disorders

Peripheral neuropathy from diabetes can result in a loss of sensation in the feet

## Peripheral neuropathy

While several degenerative disorders primarily or exclusively impact the central nervous system, there are a collection of diseases that impact the peripheral nervous system, called peripheral neuropathies. As the impacted region is the peripheral nervous system, it leads to a loss of sensation and regulatory control of extremities. These include a loss of coordination, feeling in fingers and toes and a lack of balance. The causes are yet to be fully made clear, but scientists have determined diabetes, which causes protracted periods of high blood sugar, as one of the primary causes.

Early symptoms of Parkinson's include tremors in the hands

## Parkinson's

The basal ganglia are found deep within the brain, in an area responsible for controlling movement. These nerves produce a compound known as dopamine, which is important in coordinating numerous functions, including executive functions and motor control. Although the cause is not yet clear, the basal ganglia can become impaired and begin to die. The result of this is Parkinson's disease, as the loss of dopamine gradually hampers key functions such as walking, talking and memory recall. These effects are compounded by the loss of nerves responsible for producing norepinephrine, a key compound in the sympathetic nervous system needed to regulate heart rate and blood pressure.

© Alamy / Getty

# The gut-brain axis

*How does the bacteria in your gut act like a 'second brain'?*

We all know that our mood and behaviour is controlled by the brain, but are we overlooking another important aspect of our neurobiology?

There is an increasing amount of evidence to suggest that the activity of bacteria in your gut can significantly affect your brain. This relationship is called the gut-brain axis, and while its exact mechanisms and significance haven't been fully figured out, it is thought that the microbes colonising your digestive tract are responsible for complex interactions between your digestive system and the nervous, endocrine and immune systems.

Your intestines are filled with bacteria. When you think of bacteria you probably think of the germs that make you sick, but we actually have a lot to thank these tiny microorganisms for. We rely on 'good' bacteria to help break down food, produce vital nutrients and defend us against harmful bacteria. But this could just be the tip of the iceberg. Scientists have speculated that gut microbes can send signals to the brain via three different methods.

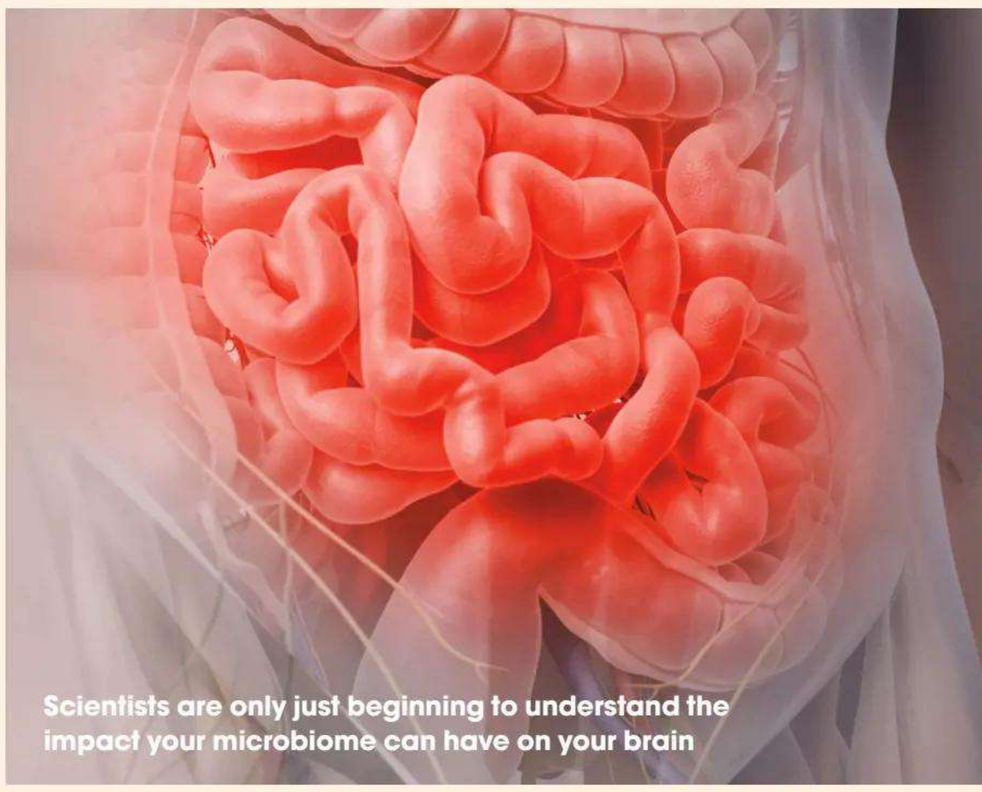
The first involves bacteria releasing neurotransmitters (chemicals that help to transmit nerve impulses) to trigger the neurons in your digestive tract, which in turn send signals to your brain via the vagus nerve. Some studies have shown that certain species of gut bacteria can produce serotonin, an important neurotransmitter that plays a role in regulating your appetite and mood.

A second proposed method is that microbes in the gut produce molecules called metabolites as by-products when they break down our food. These metabolites can stimulate an increase in the production of neurotransmitters by cells that line the gut (epithelial cells), which activate the vagus nerve. For example, a recent study found that some gut microbes can produce the fatty acids butyrate and tyramine, which promote the production of serotonin by certain cells.

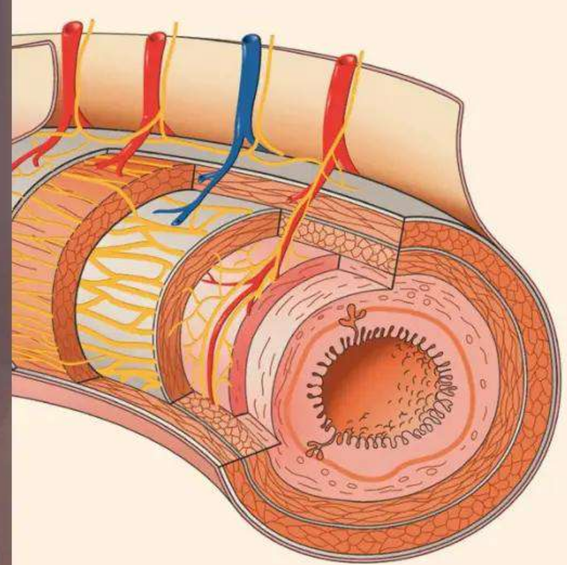
The third hypothesis is that gut bacteria can influence the brain indirectly by triggering the immune system. Gut bacteria can stimulate immune cells to produce small proteins called cytokines, which travel through the bloodstream to the brain. It is thought that these proteins can influence the development and activity of microglia (the brain's immune cells), which are responsible for removing any damaged cells at an injury site. Researchers believe microglia also play a role in the regulation of both your appetite and metabolism.

Although there are few human studies at the moment, animal studies have linked the activity of bacteria in the gut to a variety of known conditions, including Parkinson's disease, obesity, depression, anxiety, schizophrenia and cardiovascular disease, and they may also cause certain types of strokes.

While much more research will be needed to further investigate these initial findings, if links are confirmed it could revolutionise how we treat certain neurological disorders. Perhaps in the future doctors will be prescribing probiotic diets to supplement treatments.



Scientists are only just beginning to understand the impact your microbiome can have on your brain



Your intestines contain a vast network of nerves (shown left, in yellow), providing communication links between your brain and gut

## Bacterial boost

Two recent studies have shown that patients' gut bacteria can influence how well they respond to particular cancer treatments. Both studies, one from France and one from the US, collected data from patients undergoing immunotherapy, which help to combat cancer by enabling the body's immune cells to recognise and attack tumours.

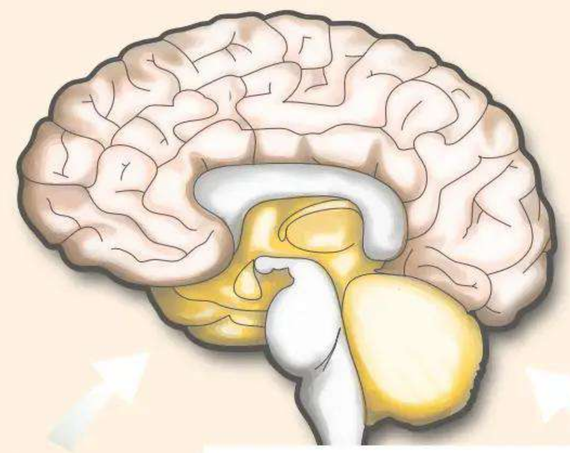
The French study involved 249 patients receiving immunotherapy for kidney, bladder or lung cancers, 69 of whom had taken antibiotics for routine infections. Antibiotics disrupt the microbiome, affecting both 'good' and 'bad' bacteria. On average, patients who took antibiotics during treatment were more likely to have relapses and did not survive as long as those who didn't. The authors then compared the differences in the patients' microbiomes and found that the presence a species called Akkermansia muciniphila was linked to the improved immunotherapy results.

The US study also compared the different gut bacteria present in 112 melanoma patients. Patients who responded well to treatment were more likely to have more diverse microbiomes and higher numbers of certain beneficial species including Clostridiales and Faecalibacterium. Patients with more of these 'good' bacteria were found to have more cancer-killing immune cells in their tumours.

The results from both studies hold a lot of promise. The hypothesis is that by supporting a healthy microbiome, immunotherapy is more likely to be effective at shrinking tumours.

# Gut feeling

How can your microbiome influence your brain?

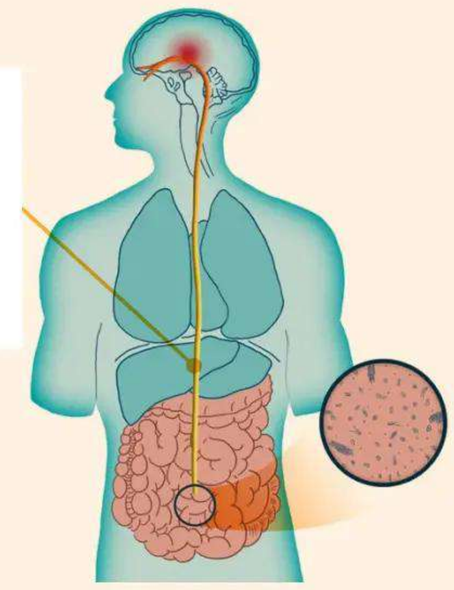


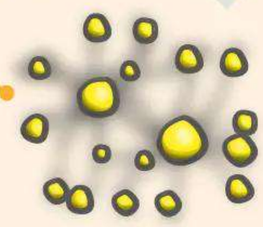
**Neurotransmitter production**

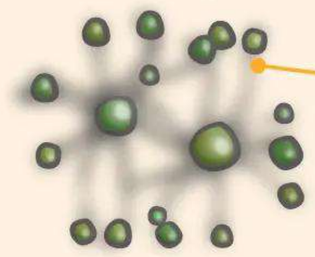
Some bacteria have been found to stimulate the production of serotonin — a neurotransmitter that helps regulate mood — by cells in the intestinal wall.

**Vagus nerve**

The vagus nerve provides a communication pathway between the gut and the brain.

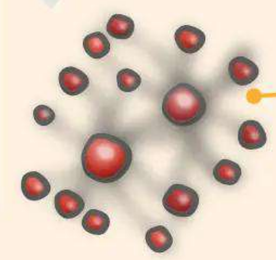






**Immune stimulation**

Bacteria can encourage immune cells to release small proteins called cytokines, which can affect immune cells in the brain.

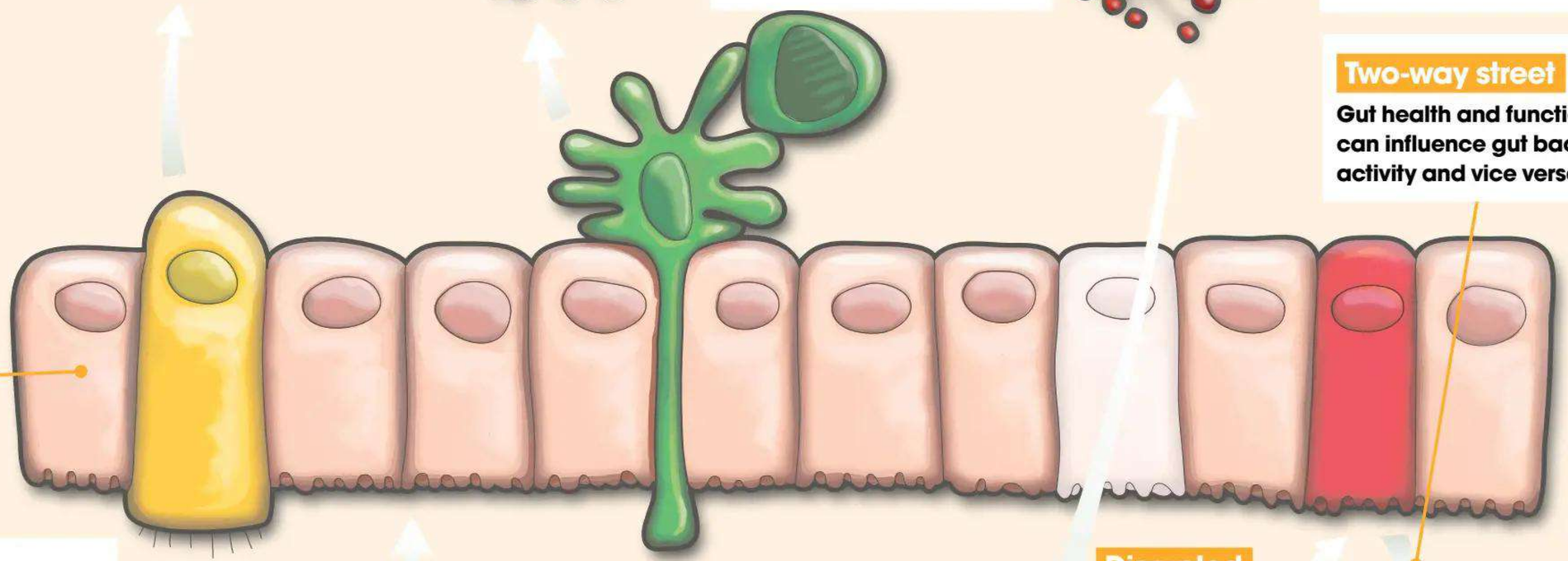


**Metabolite production**

The by-products of bacteria metabolism can affect the activity of cells in the blood-brain barrier.

**Two-way street**

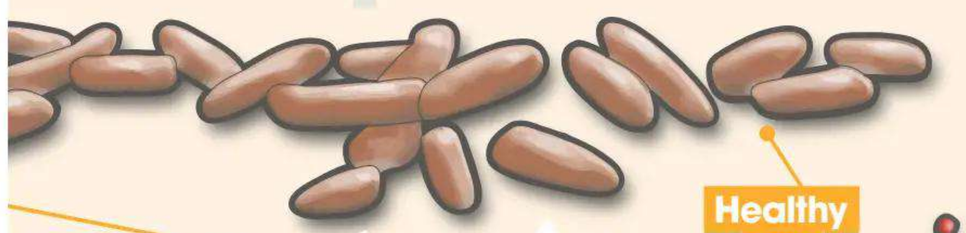
Gut health and function can influence gut bacteria activity and vice versa.



Intestinal wall

**Positive influences**

Probiotic supplements with good bacteria and prebiotic foods full of fibre that nourish our good bacteria can help to promote a healthy microbiome.

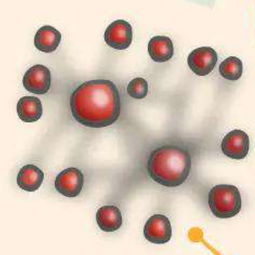


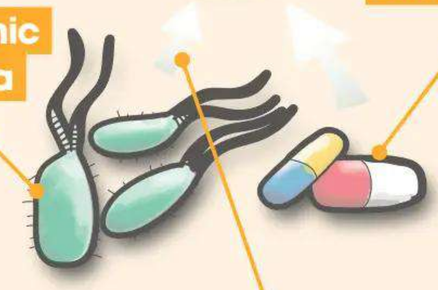
Healthy gut bacteria

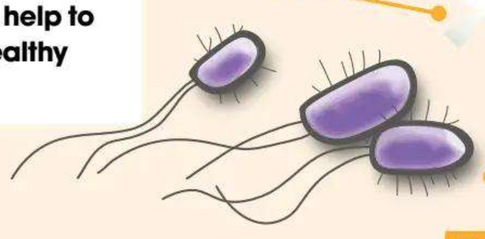
Disrupted gut bacteria

Antibiotics

Pathogenic bacteria







Beneficial bacteria

Probiotics

Metabolites

**Negative influences**

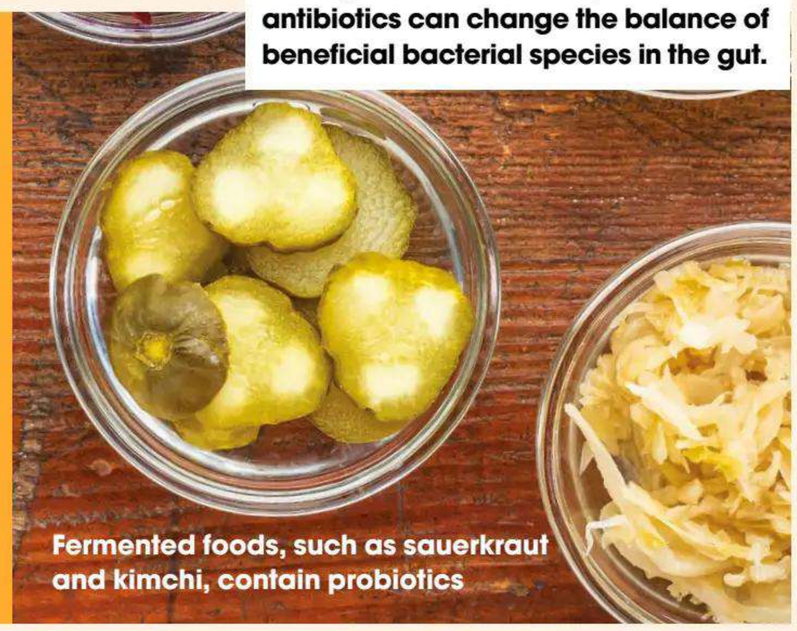
Pathogenic bacteria and/or the use of antibiotics can change the balance of beneficial bacterial species in the gut.

## Probiotics and prebiotics

Given the potential impacts our gut bacteria can have on our overall health, the old adage that states 'you are what you eat' is becoming increasingly appropriate.

We can promote the growth of good bacteria through our diets by incorporating probiotics (foods containing live good bacteria) and prebiotics (foods containing beneficial plant fibres). Probiotics can be found in certain yoghurts, cheeses and fermented foods. Prebiotics, on the other hand, are used as a food source for beneficial bacteria to grow and survive in the gut. When they digest the fibre we eat from vegetables, nuts and fruits they excrete short-chain fatty acids as waste products, which are great for nourishing our intestines and reducing inflammation.

Research suggests we need a diverse range of bacteria to have a really healthy gut, but modern high-fat and high-sugar diets have been found to decrease the number of different species of bacteria living in our intestines.



Fermented foods, such as sauerkraut and kimchi, contain probiotics

© Thinkstock; Getty; Illustration by The Art Agency / Nick Sellers

# The science of pain

*Our internal alarm system works around the clock to keep us safe from harm*

Millions of sensitive nerves guard our tissues, listening for physical danger. These pain sensors, or nociceptors, detect temperature, pressure and chemical signals. They all have a high threshold for activation and only send messages when the body is at risk of harm.

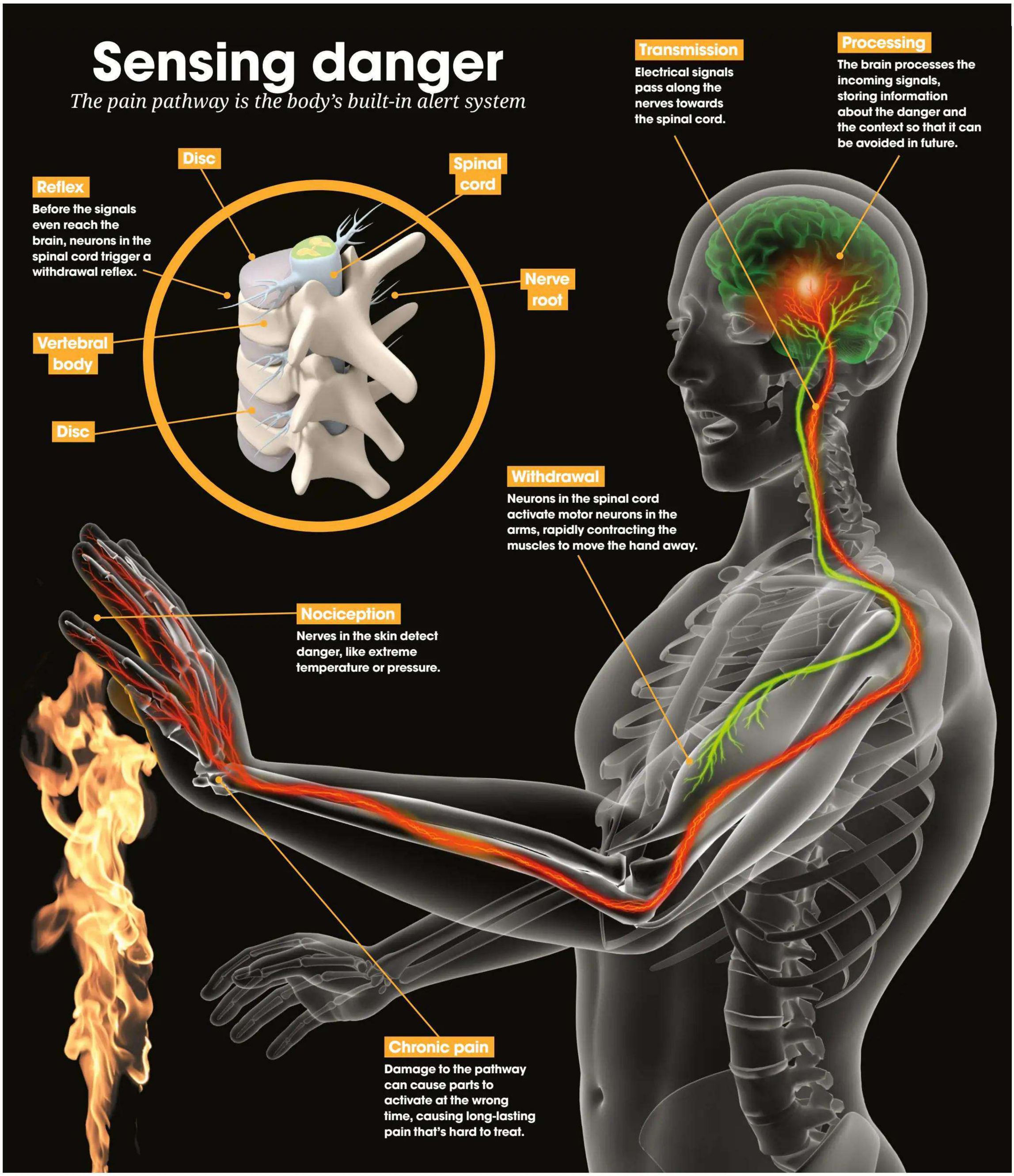
If skin temperature rises above 40 degrees Celsius or dips below 15 degrees Celsius, thermal nociceptors start to fire. If pressure exceeds three kilograms per centimetre squared, or if the skin stretches or tears, mechano-nociceptors kick into action. And if cells become damaged and start leaking their contents, chemical nociceptors switch on.

A rapid response to nociceptor activation is crucial. If you put your hand in a flame, your body needs to react in fractions of a second. Nociceptors send their signals to the spinal cord, which manages the first step of the response. It can process some of the information without the brain, triggering a rapid withdrawal reflex. This is the very simplest form of damage control, and even primitive animals sense and respond to harm in this way. But pain is more than just a reflex.

As the hand pulls away from the fire, the signal from the nociceptors passes up the spinal cord towards the brainstem. In the brain it enters the cerebral cortex, responsible for cognition and consciousness. Processing here ties the incoming sensory signals to memory and emotion, producing the complex feeling of pain. The unpleasant experience that follows helps us to remember harmful activities and to avoid them in the future.

# Sensing danger

*The pain pathway is the body's built-in alert system*




© Getty; Illustration by The Art Agency/Barry Croucher

# The different types of pain

Pain can be short-term (acute) or long-term (chronic). It can be mild, uncomfortable, distressing or debilitating. It can feel achy, dull, raw, sharp, stabbing, throbbing or burning. It might be constant or it might come and go. But beneath these different experiences, all pain falls into two main categories: nociceptive and neuropathic.

Nociceptive pain is the normal response to tissue damage. Pain nerves sense extreme temperature, extreme pressure or harmful chemicals and they send signals to the brain. This alerts us to danger, encourages us to rest the injured area and reminds us to avoid the situation in the future.

Neuropathic pain, by contrast, does not serve a useful purpose. It is the result of nerve damage. Certain injuries, illnesses and infections harm pain-sensing neurons, and if the body cannot make repairs, they can start to misfire. The nerves send pain signals when there shouldn't be any pain, and the brain can't tell the difference. This type of pain is particularly challenging to treat.

The arthritic joints in the hand on the right cause nociceptive pain

## Can we measure pain?

**How do you convert the subjective experience of pain into cold hard numbers? One of the first attempts was to use a dolorimeter, a device that would push or burn the skin until the patient said 'ouch'. This would reveal their pain threshold; the amount of pressure or heat they could tolerate. Today, the most common measure of pain is simply to ask someone how they're feeling and how much it hurts on a scale of one to ten. However, scientists at the University of Colorado have been using brain scans to make this a more scientific test.**

**Using a dolorimeter-like approach, they applied heat to the skin, but instead of waiting for people to say 'ouch', they watched their brains. In total, 114 people took part in the study, which also included scientists from three other US universities. Each person experienced a range of different temperatures, which revealed a signature pattern of brain activity that predicted the level of physical pain they felt. The pattern differed from emotional pain and decreased with painkillers, providing an objective way to see how much something really hurts.**

# Acute vs chronic pain

Spot the difference between these two major types of pain

| Acute | | Chronic |
|---|---|---|
| *Resolves after the illness or injury gets better* | Time | *Continues long after the injury heals* |
| *Nerve activation in response to actual tissue damage* | Cause | *Not always clear* |
| *Alert system to avoid damage and allow time to heal* | Purpose | *No clear biological purpose* |
| *Focused on tackling the underlying cause of the pain* | Treatment | *Focused on managing pain and minimising the impact* |

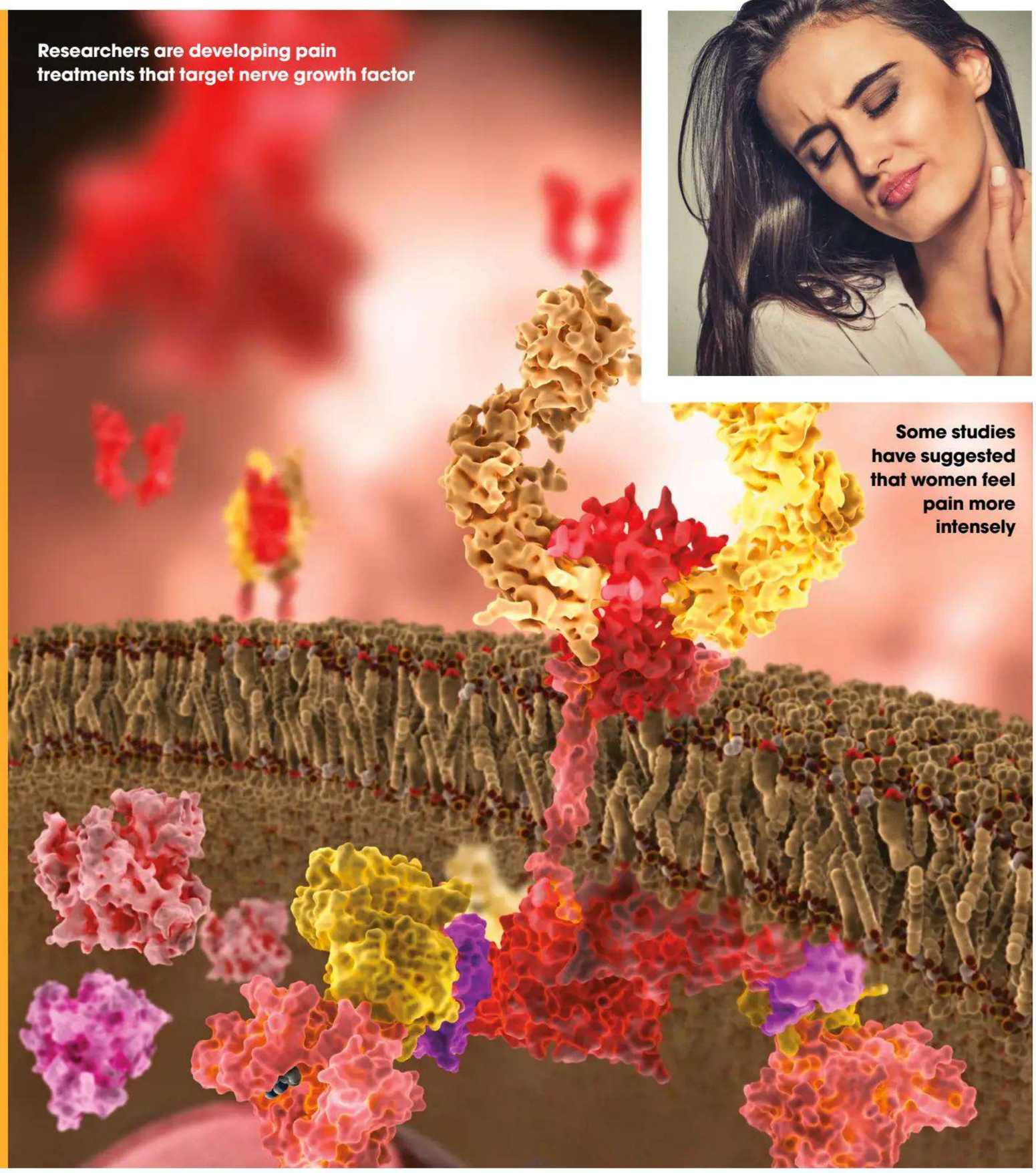
## Treating chronic pain

Over-the-counter painkillers tend to target inflammation, which means they are not always particularly useful for chronic pain. Opiate painkillers, like codeine and morphine, can stop pain messages reaching the brain, but they are addictive and their effectiveness decreases over time, so they are not recommended for long-term treatment. Other options include antidepressants and anticonvulsants; these actually change the brain's chemistry, but they don't always work for every person.

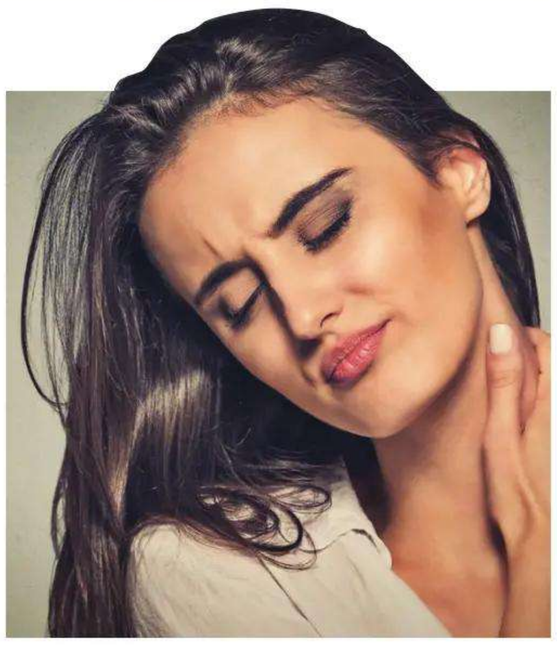
The pharmaceutical industry has been looking at a chemical produced by the brain called nerve growth factor (NGF). NGF changes the pain sensitivity of nerves, and blocking its activity in animals has been shown to help to reduce pain, but trials conducted in humans in 2010 had dangerous side-effects, including loss of blood to the bones. There is still a lot of work to do to find out whether they are safe to use.

Physical and psychological therapy can help to provide some distraction, but many people struggle daily with chronic pain. Without a cause for doctors to treat, it can be extremely hard to manage.

**"Nerve growth factor changes the pain sensitivity of nerves, helping to reduce pain"**



Researchers are developing pain treatments that target nerve growth factor



Some studies have suggested that women feel pain more intensely

© Getty; Science Photo Library

# Killing pain

Damage to our tissues causes mechanical and chemical changes that activate pain-sensing neurons. The neurons send signals to the spinal cord, which relays them to the brain. Painkillers try to block this process by interfering with it at different stages.

The most common over-the-counter painkillers attack the very start of the pain-sensing chain. Non-steroidal anti-inflammatory drugs (NSAIDs) – like ibuprofen – try to remove some of the chemical signals that activate pain-sensing neurons. They do this by interfering with an enzyme called cyclooxygenase (COX). COX makes chemical messengers called prostaglandins, which promote inflammation. Blocking COX dampens the inflammatory response, relieving the pain.

The next step in the pathway is the transmission of pain signals towards the spinal cord. Local anaesthetics work here. For nerve cells to fire they need to transport sodium ions across their membranes. These carry a charge, which sets up the electrical signal. Local anaesthetics block the channels that transport the ions, stopping pain signals in their tracks.

The strongest painkillers, the opioids, work on the next part of the pathway: preventing signals getting to the brain. This group includes codeine, morphine and the illegal drug heroin. They act on the spinal cord and brainstem to stop pain messages passing through.

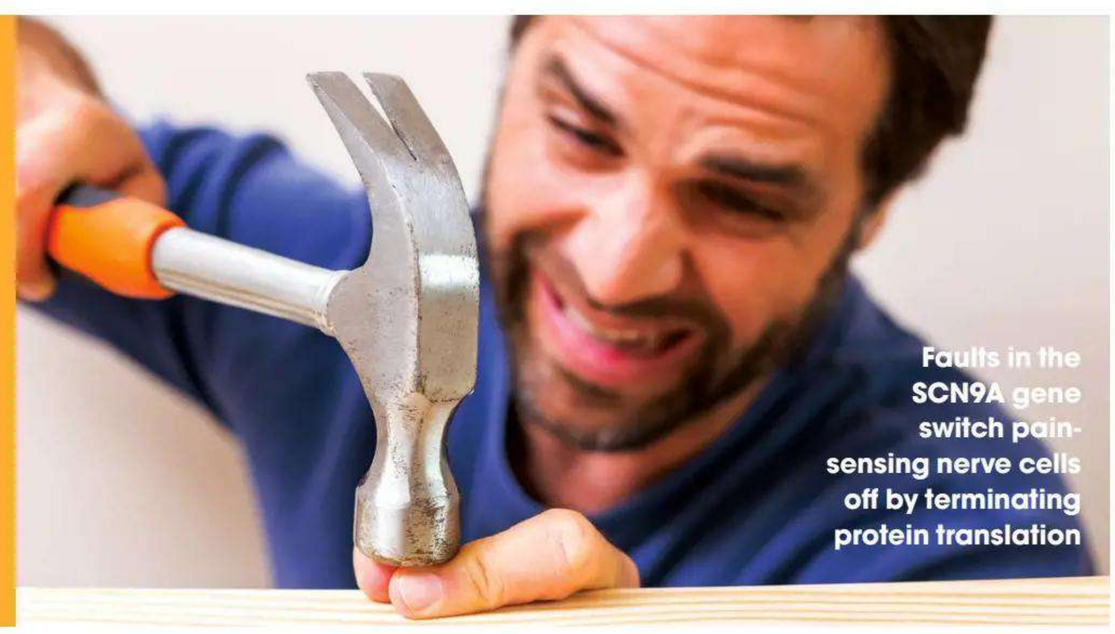
Finally, there are the general anaesthetics, which work on the very last link in the chain. They stop the brain being aware of pain by interfering with the way that nerve cells pass signals to each other. Each kind of painkiller has advantages and disadvantages for different situations.

**Painkillers interfere with the way our body senses and responds to damage**

## People who don't feel pain

Very rarely, people are born without the ability to feel pain. A defect in a gene called SCN9A makes it impossible for their pain-sensing nerve cells to transmit signals. This makes it impossible for them to tell when hot becomes burning, when cold becomes freezing or when pressure becomes crushing.

The SCN9A gene codes for a protein that makes a part of a structure called a sodium channel. Sodium ions carry the electrical signals along nerves, and these channels control their movement. With the mutation in the gene, the channels don't fit together and the pain-sensing neurons can't fire. While this might sound like a superpower, but being unable to sense pain makes people with these genetic faults much more likely to do themselves harm.



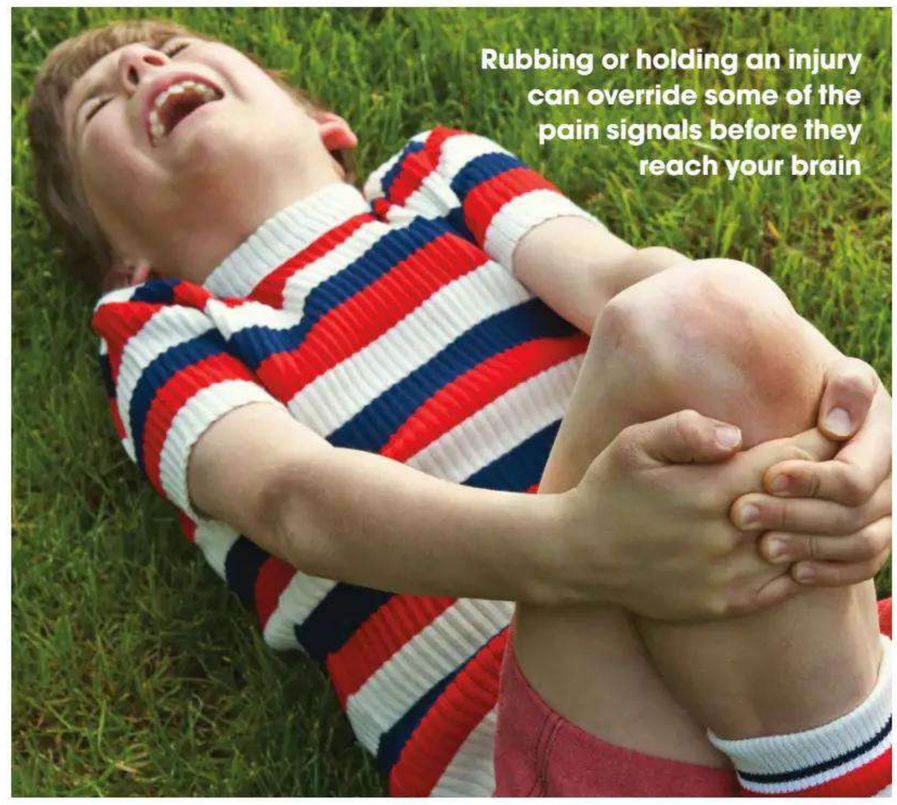
**Faults in the SCN9A gene switch pain-sensing nerve cells off by terminating protein translation**

# Gate control theory

Have you ever stubbed your toe and immediately reached down to grab your foot? Or burnt your finger and instinctively put it into your mouth? This is gate control theory at work.

Pain signals travel from the site of an injury towards your brain along thin nerve fibres. As they enter the spinal cord they compete for bandwidth with the other nerves that are also trying to send messages to your brain. This includes larger fibres that carry non-painful signals, like pressure and touch. Both the painful and non-painful signals are trying to reach the projection cells of the spinal cord, but there's a gatekeeper in the way.

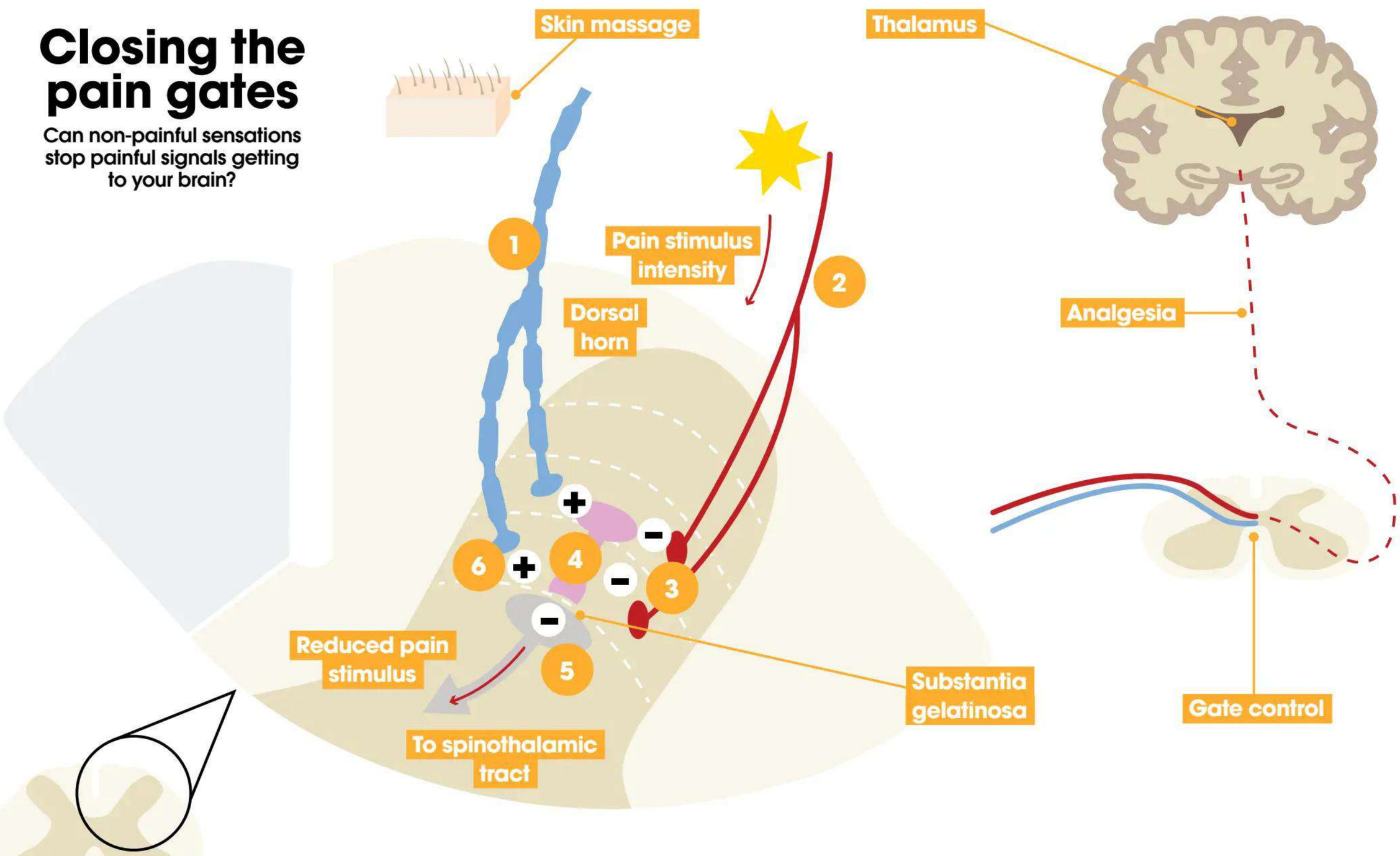
The gatekeeper is an inhibitory neuron. It listens for signals from both the pain fibres and the sensory fibres and decides which can send its signals to the projection neuron. When a pain signal arrives on its own the interneuron lets it through the gate, but when a sensory signal is passing the gate the pain signal closes. So if you put pressure on your stubbed toe it can actually stop some of the pain signals from reaching your brain, naturally blocking out the unpleasant feeling.



Rubbing or holding an injury can override some of the pain signals before they reach your brain

## Closing the pain gates

Can non-painful sensations stop painful signals getting to your brain?




**1 C-fibre**
When the skin senses touch, pressure and vibration, signals travel along large, slow, insulated nerve fibres.

**2 A-beta fibre**
When the skin detects damage, signals travel along thin, fast, uninsulated nerve fibres.

**3 Pain reduction**
When the touch-sensitive nerve fibres are active, fewer pain signals get through the gate.

**4 Inhibitory interneuron**
A nerve cell sits between the two fibres, listening for signals and deciding which can pass through.

**5 Pain gate**
The two types of signal compete to pass through the 'gate' into the spinal cord.

**6 Sensory overload**
The gate gives preference to the larger A-beta fibres, allowing non-painful touch signals through.

© Getty

# What is the blood-brain barrier?

*How does this gateway control the molecules that pass from the blood into the brain*

The blood-brain barrier (BBB) is an essential group of cells that line the blood vessels in the central nervous system (brain and spinal cord). They allow passage of materials between the clear fluid surrounding the brain (cerebrospinal fluid) and the red blood cells in arteries, veins and capillaries. The key advantage of having such a barrier is that it prevents large micro-organisms passing into the brain and causing infections. While infections in other areas are common (such as after a cut finger, or mild chest infections), those affecting the brain are much rarer. However when they do occur (eg meningitis), they are potentially life threatening as they are very difficult to treat.

The tight junctions between cells regulate the size and type of particle that pass between them, including oxygen molecules, carbon dioxide molecules, nutrients and hormones. Since it's so effective, it also stops medications from entering the brain (such as certain antibiotics), so while they are effective in the rest of the body, they are ineffective in this vital organ. Overcoming this is a major aim of doctors in the next decade, and the battle has already started. Manipulating the blood-brain barrier's natural transport mechanisms and delivering drugs within nanoparticles to squeeze through the tight junctions are just two examples of the modern techniques that are under development.

## Breaking down the barrier

This built-in gateway is the main line of defence for the central nervous system

**1 Just passing through**
Some ions are transported out of the blood cells and into the astrocytes, and then out of the astrocytes and into neurons in the brain.

**2 Astrocyte**
These numerous star-shaped cells provide biochemical support to the endothelial cells, and also play an important role in transportation and repair.

**3 Special transport**
Active and passive transporters across this membrane can overcome some of these problems, and be manipulated to deliver medications to the correct place.

**4 Highly charged**
Highly charged ions are repelled, meaning that some medications are ineffective in the brain.

**5 A tight squeeze**
The tiny gaps between cells regulate the size and type of particle that are able to fit through.

**6 Lipophilic**
Substances rich in lipids can diffuse across the barrier with relative ease.

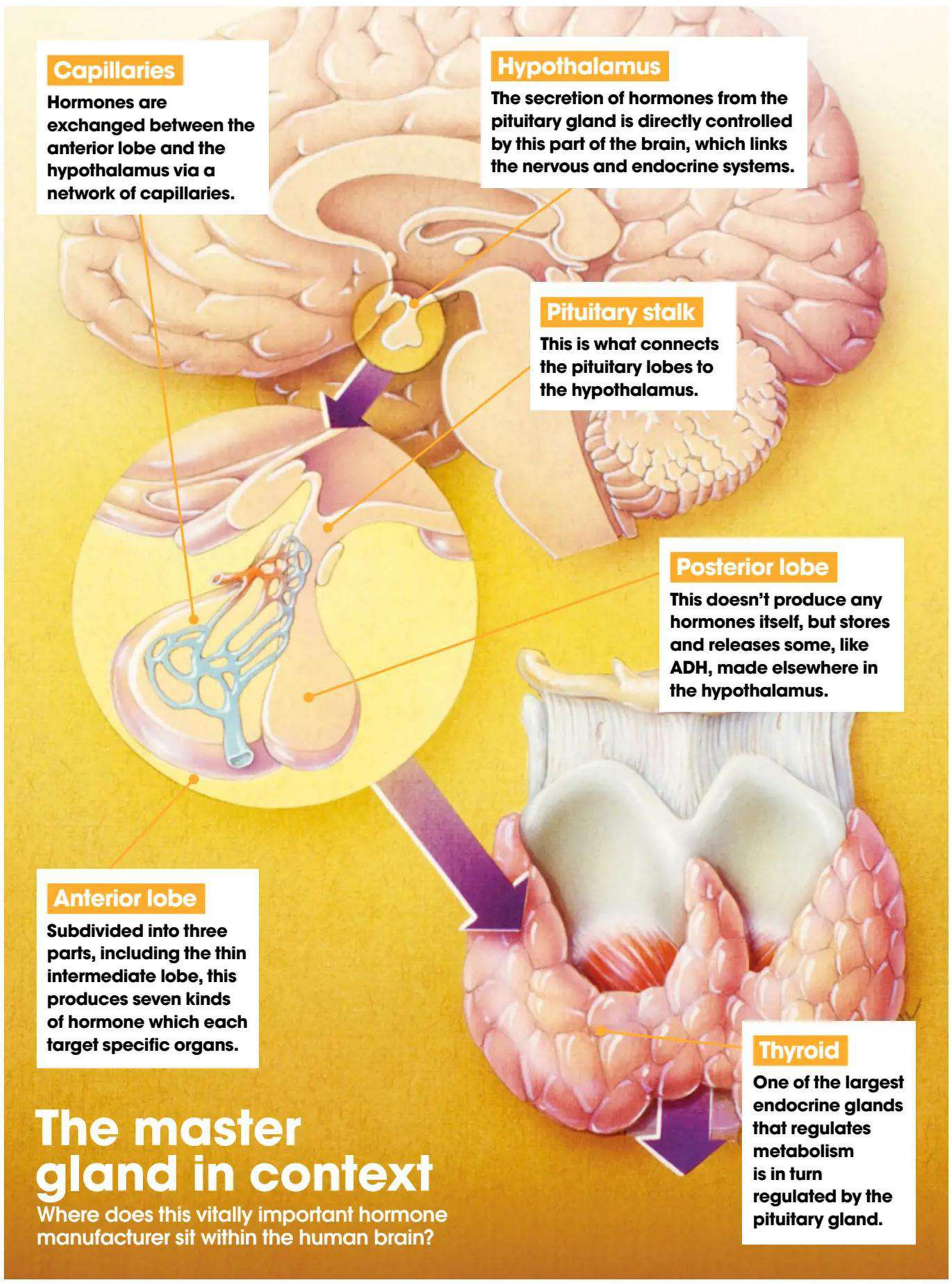
## Crossing the BBB

The endothelial lining of the blood-brain barrier loves lipids (fatty molecules), but it hates particles with high electrical charges (ions) and large substances. Thus the ideal substance is small, rich in lipids and has a low electrical charge. Barbiturates are such an example, as they freely flow across the blood-brain barrier to suppress brain function; they act as sedatives and antidepressants. However this free movement comes with risks – too much of it will accumulate and slow the brain to a point where you can lose consciousness and even stop breathing.

© SPL

# Pituitary gland up close

*What does this hormone factory do and why couldn't we live without it?*




## The master gland in context

Where does this vitally important hormone manufacturer sit within the human brain?

The pea-sized pituitary gland is found at the base of the brain, close to the hypothalamus. At a glance, it looks a relatively insignificant part of the brain, but it actually plays a role in many vital systems.

Often referred to as the 'master gland', it not only releases hormones that control various functions, but it also prompts the activity of other glands like the ovaries and testes.

The pituitary gland comprises three sections called lobes: the anterior, the posterior and the intermediate – the latter of which is considered part of the anterior lobe in humans. These work together with the hypothalamus, which monitors hormones in the blood and stimulates the pituitary gland to produce/release the appropriate hormone(s) if levels fall too low.

The anterior lobe produces seven important hormones, which include those that regulate growth and reproduction. Adrenocorticotropic hormone (ACTH) targets the adrenal glands to produce cortisol and controls metabolism, while luteinising hormone triggers ovulation in women and stimulates testosterone production in men. The posterior lobe, meanwhile, doesn't generate any hormones itself, but stores two: antidiuretic hormone (ADH), which decreases urine production by making the kidneys return more water to the blood, and oxytocin, which tells the uterus to contract during childbirth and also prompts milk production.

## Gigantism in focus

The pituitary gland also produces growth hormone, which in adults controls the amount of muscle and fat in the body and plays a key role in the immune system. In children, of course, growth hormone has a very noticeable effect in increasing height and bulk until adulthood. However, sometimes the pituitary gland becomes hyperactive – often as a result of a benign tumour – and produces excess growth hormone. In these cases, a person can grow to a far-beyond-average height, with hands, feet and facial features growing proportionally. While this might not see, so bad, gigantism is nearly always accompanied by other health issues, such as skeletal problems, severe headaches and more life-threatening conditions like heart disorders. If diagnosed early, treatment such as drugs that inhibit growth hormone production and surgical removal of the tumour can help avert the more serious conditions of gigantism.

© Alamy

# the science behind your accent

*How an accent is generated by the brain and shaped over time*

There are over 7,000 languages used across the world, and within each of these languages there are many different dialects and accents. But how did people develop such different ways of speaking, and how do our bodies learn to produce and maintain the same sounds?

An accent is a specific way a person enunciates and pronounces words in a language. While different dialects range in their unique vocabulary and grammar rules, accents are the different sounds that can be made when using the same vocabulary and grammar.

New accents emerge when groups of people develop their own identities and are based on two main factors: human nature and isolation. Human nature involves people's tendency, especially historically, to form groups and remain within those groups for long periods of time. The second factor is rooted in these groups being separated from others, allowing them to evolve unique accents over time. In today's world, accents from all around the globe can be heard as people travel and communicate through media, telephones and the internet.

# voices in the mind

What role does the brain play in forming and controlling your accent?

## 1 Listening and understanding

The brain is better at processing accents it's encountered. The ear conveys sound, but if the brain is unable to make sense of foreign sounds, it replaces them with those it understands.

## 2 Wernicke's area

Located behind your ear, Wernicke's area processes the sound of accents.

## 3 Broca's area

This region of the brain is most active just before you speak. Broca's area turns your brain's thoughts into sounds.

## 4 Motor cortex

After receiving the information from Broca's area, the motor cortex controls how your mouth moves. The shapes your lips, tongue and facial muscles make impact the sounds that leave your mouth.

## 5 Cerebellum

Details of how the back of the brain contributes to language are largely unknown, but the cerebellum impacts how we use separate syllables in speech.

## 6 A different accent

When you put on an accent different to your own, an area deep inside the left side of your brain called the left anterior insula is activated.

## Crying with an accent

Accents are most often analysed during in-depth conversational speech. But did you know that your accent began developing before you could speak? Studies have shown that even in the first weeks of your life you already pick up some of the intonation of your native language and accent, mimicking these melodies when crying. Scientists believe that the first learnings of an accent take place while babies are still in the womb. What they hear during the months prior to being born impact their first sounds. During an experiment with 60 babies – 30 from French-speaking families and 30 German-speaking – researchers discovered that the rising and falling pitches in their cries matched the patterns of their native languages.

Crying babies can imitate speech rhythms and intonation

© Getty

In some regions of the brain, half the brain cells are lost during childhood

# What is brain plasticity?

For some people, moving to another country or region can cause their accent to change, but most of the sounds from your original accent are likely to remain permanent from around the age of 12. This is due to changes in brain plasticity. This is your brain's ability to adapt, modifying connections in the brain in response to the environment.

When you're born, your brain has the ability to develop any accent it's exposed to. But as you age, your brain becomes less flexible. You will keep your primary accent and won't pick up another language as easily – even when learning a second language and spending significant time using a new accent, you won't completely lose your original one. The purpose of brain plasticity is to stabilise new information once it's learned. Within the first year of your life, your ability to hear the sounds of different languages and accents diminishes. One study showed that Japanese babies were able to hear the difference between 'la' and 'ra' when they were six months old, but due to not being exposed to English speakers who used these sounds, Japanese babies aged between 10 and 12 months were unable to notice these same differences.

After 42 years with an American accent, Robin Jenks Vanderlip hit her head and now speaks with a Russian one

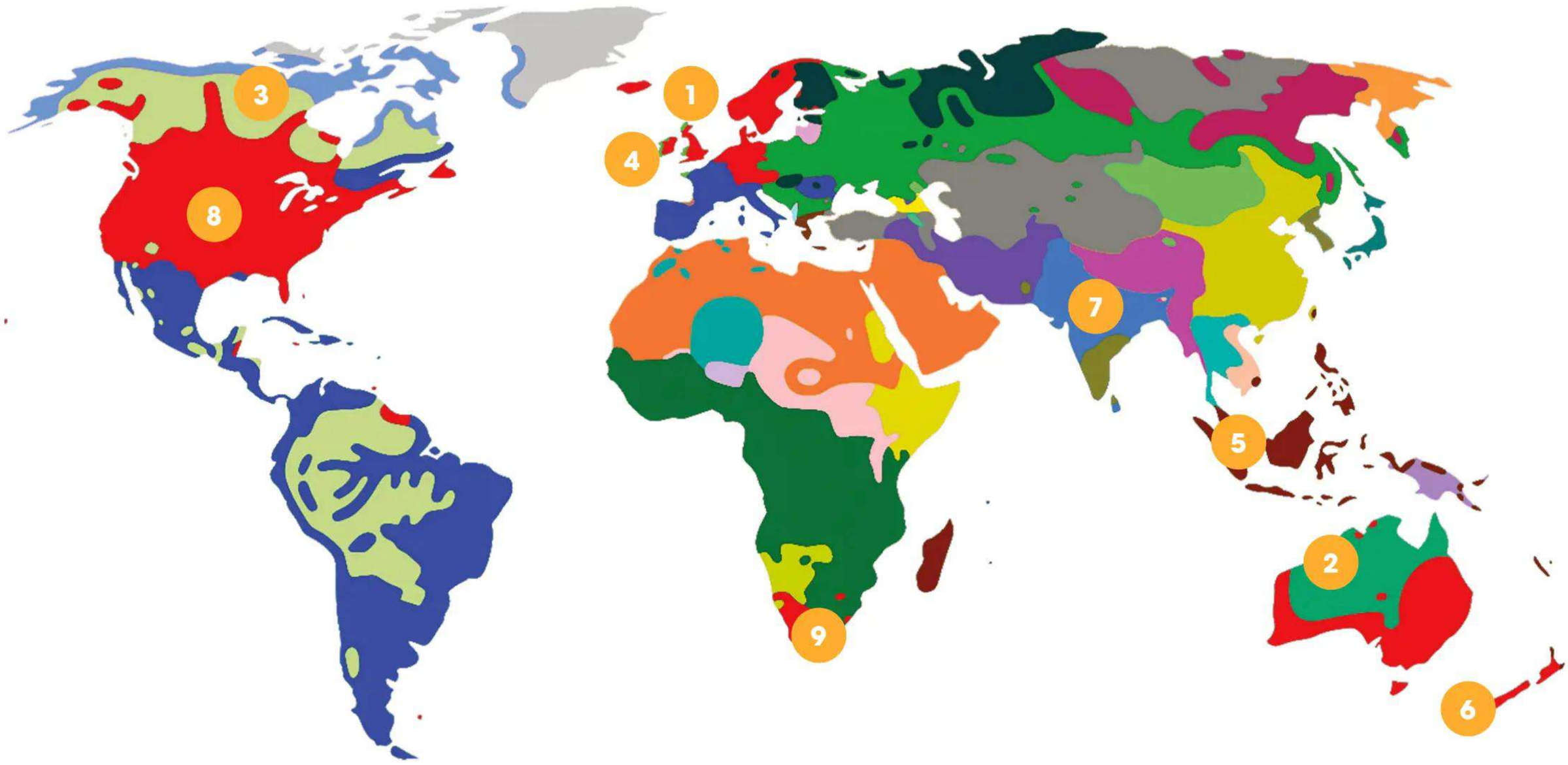
## Foreign accent syndrome: Waking up foreign

Although extremely rare, it's possible for people to suddenly begin to speak with an accent they've never associated with. Since foreign accent syndrome was first recognised in 1907, there have only been around 100 cases of this happening. In these cases, people have complained of headaches or sustained injury to the head through strokes or other traumatic brain injuries before waking up with a new, foreign accent.

In 2015, Michelle Myers from Arizona went to sleep with what she described as "a blinding headache". When she woke up and spoke, she was surprised to hear a British accent in place of her usual American one. Although startling, this wasn't the first time it had happened to her. In previous instances, Myers had adopted Irish and Australian accents, but unlike her long-term British accent, these incidents only lasted a week. Scientists think that foreign accent syndrome changes people's pronunciation due to injury in Broca's area of the brain.

# Ten English-speaking accents

*How much can the same language vary when used around the world?*




### 1 British English

**Language family:**

Germanic

Celtic

A single 'British accent' doesn't exist, as pronunciation patterns have evolved differently by area. 'Received pronunciation', also known as Queen's English, is largely regarded as the UK's standard, despite only accounting for three per cent of the country.

### 2 Australian English

**Language family:**

Australian aborigina

Germanic

Australian accents don't have a strong 'r' sound at the end of words such as 'teacher'.

### 3 Canadian English

**Language family:**

Germanic

Amerindian

Inuit-Aleut

The vowel sounds made in Canadian accents are more nasal than other English accents, such as American English, which produce vowels at the back of the throat.

### 4 Irish English

**Language family:**

Germanic

Celtic

Many accents replace the 'th' sound in words such as 'three' with a single t, making it sound like 'tree'.

### 5 Singaporean English

**Language family:**

Austronesian

Accents include an extension of the last vowel sound in words. 'Th' is replaced with a 'd' sound .

### 6 New Zealand English

**Language family:**

Austronesian

Germanic

The vowel sound 'e', such as in the word 'pen', usually sounds like an 'i', making the word sound like the British English word 'pin'.

### 7 Indian English

**Language family:**

Indo-Aryan

Dravidian

The vowel sound 'e', such as in the word 'pen', usually sounds like an 'i', making the word sound like the British English word 'pin'.

### 8 American English

**Language family:**

Germanic

Amerindian

Inuit-Aleut

Intonation is one of the key factors separating American English and British English. While British accents include mostly falling pitches, American accents often increase in pitch after the main stressed syllable.

### 9 South African English

**Language family:**

Niger-Congo

Khoisan

Germanic

A common trait of some South African English accents is the 'a' sound being pronounced as 'eh' instead of 'ay'. For example, someone might say 'South Efrica'.

### 10 International English

**Language family: N/A**

Due to there being so many variations of the English language, people who learn English as a second language can have unique and variable accents based on the resources they used to learn and distinguishing features of their own language.

**"When she woke up and spoke, she was surprised to hear a British accent in place of her usual American one"**

© Getty / Eric Gaba

# Ten Weird things you never knew about your brain

*Discover the science and psychology behind the brain's fascinatingly quirky and unique design*

BIOLOGY

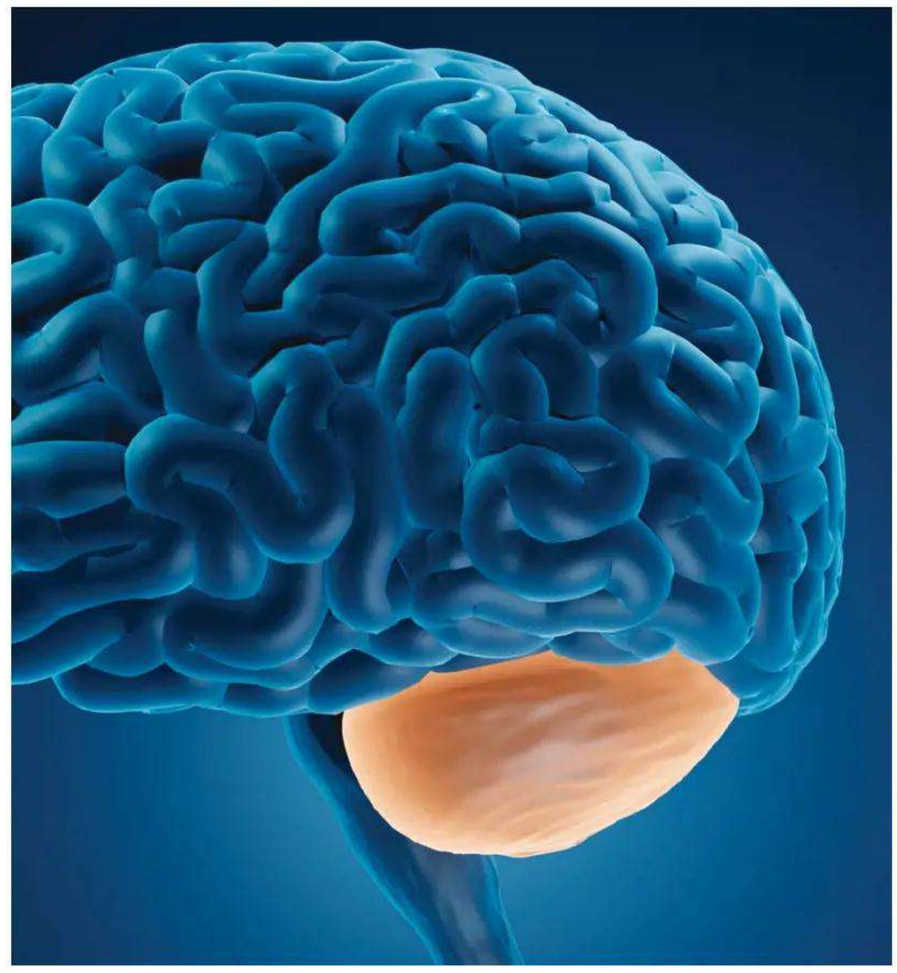
# It's possible to live without most of it

1

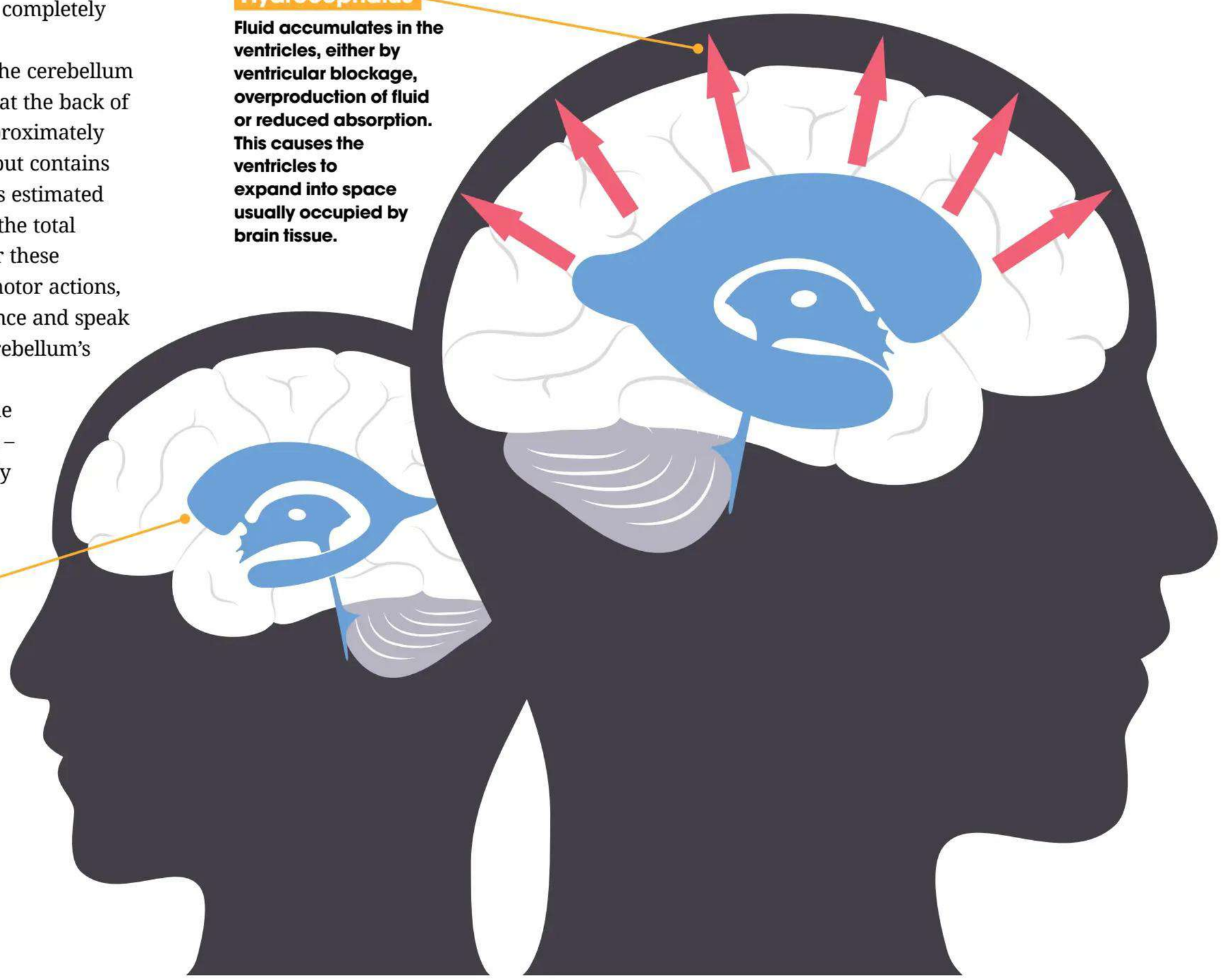
In 2015, a team of neurologists and radiologists from Jinan Hospital in Shandong Province, China, wrote to the journal Brain reporting a rare and unusual finding. A 24-year-old female patient had been admitted with symptoms of nausea and vomiting. These were new symptoms, but she'd also suffered from dizziness and walking difficulties for most of her life. Despite these challenges, she was married and had enjoyed a successful pregnancy. The doctors referred her for computer tomography (CT) and magnetic resonance imaging (MRI) scans to search her brain for a cause of these symptoms. What they observed was a disorder so rare that less than ten people throughout the world were known to be living with it. The patient was completely missing her cerebellum.

Known as the 'little brain', the cerebellum is a distinct structure that sits at the back of the brain. It only occupies approximately ten per cent of brain volume but contains a dense abundance of neurons estimated to be well over 50 per cent of the total neurons in the brain. Together these neurons work to coordinate motor actions, allowing us to walk with balance and speak with precision. Despite the cerebellum's integral function, sufferers of cerebellar agenesis – where the structure is completely absent – are sometimes able to mentally develop normally aside from hampered motor functions.

Loss of brain tissue can also be seen in sufferers of hydrocephalus, a condition where cerebrospinal fluid accumulates in the brain. In extreme cases, the fluid can accumulate to such an extent that it doesn't leave much room in the skull for anything else, including brain matter. In Marseille, France, a 44-year-old male was found to be suffering from a case of hydrocephalus so severe that he was estimated to be missing over 50 per cent of his brain tissue. And yet the man had led a relatively normal life, maintaining a job and raising a family, showcasing the brain's incredible capacity to adapt and utilise what tissue it has to perform necessary functions.



**Sufferers of cerebellar agenesis are completely missing their cerebellum, yet can sometimes live relatively normal lives**




© Getty

# Wrinkly brains are smarter

2

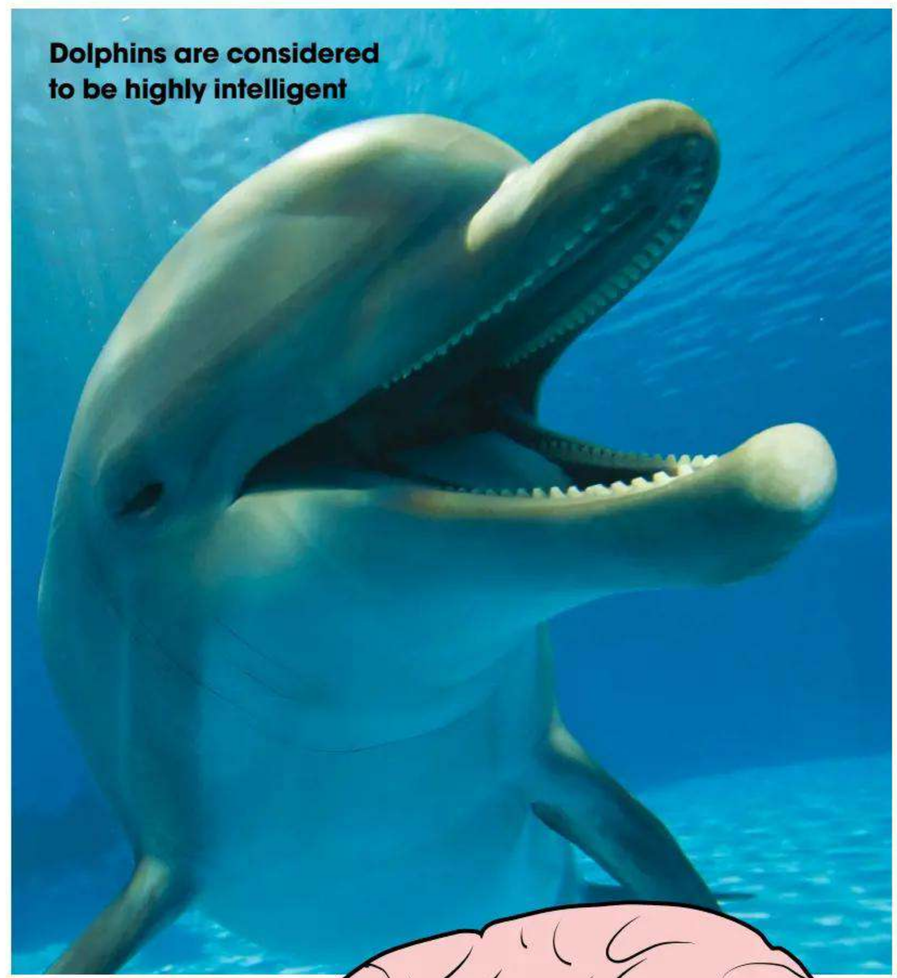
Sometimes we encounter people who have a high opinion of their own intelligence, and we might call them 'big-headed'. This is because we naturally associate a big brain with high intelligence – that more brain means more thinking power. But it would be more accurate to call them 'wrinkly brained'. The exterior of the human brain isn't a shiny, smooth surface, but instead is a wrinkled mass of folds that form as a result of 'gyrification'. As we develop, our brains expand into a limited space defined by the available room in the cranium. To maximise the amount of brain within this limited space, the brain expands and then folds in on itself, forming layers of gyri (bumps) and sulci (grooves).

The result of gyrification is to increase the surface area of the brain. Increasing surface area in a limited space is a useful trick employed by biology all the time. Elsewhere in the human body, our lungs utilise tiny alveoli sacs and our gut uses finger-like villi to vastly increase the surface area available for exchanging gases and nutrients. The brain's high surface area allows it to pack as many brain cells, or neurons, inside our heads as possible.

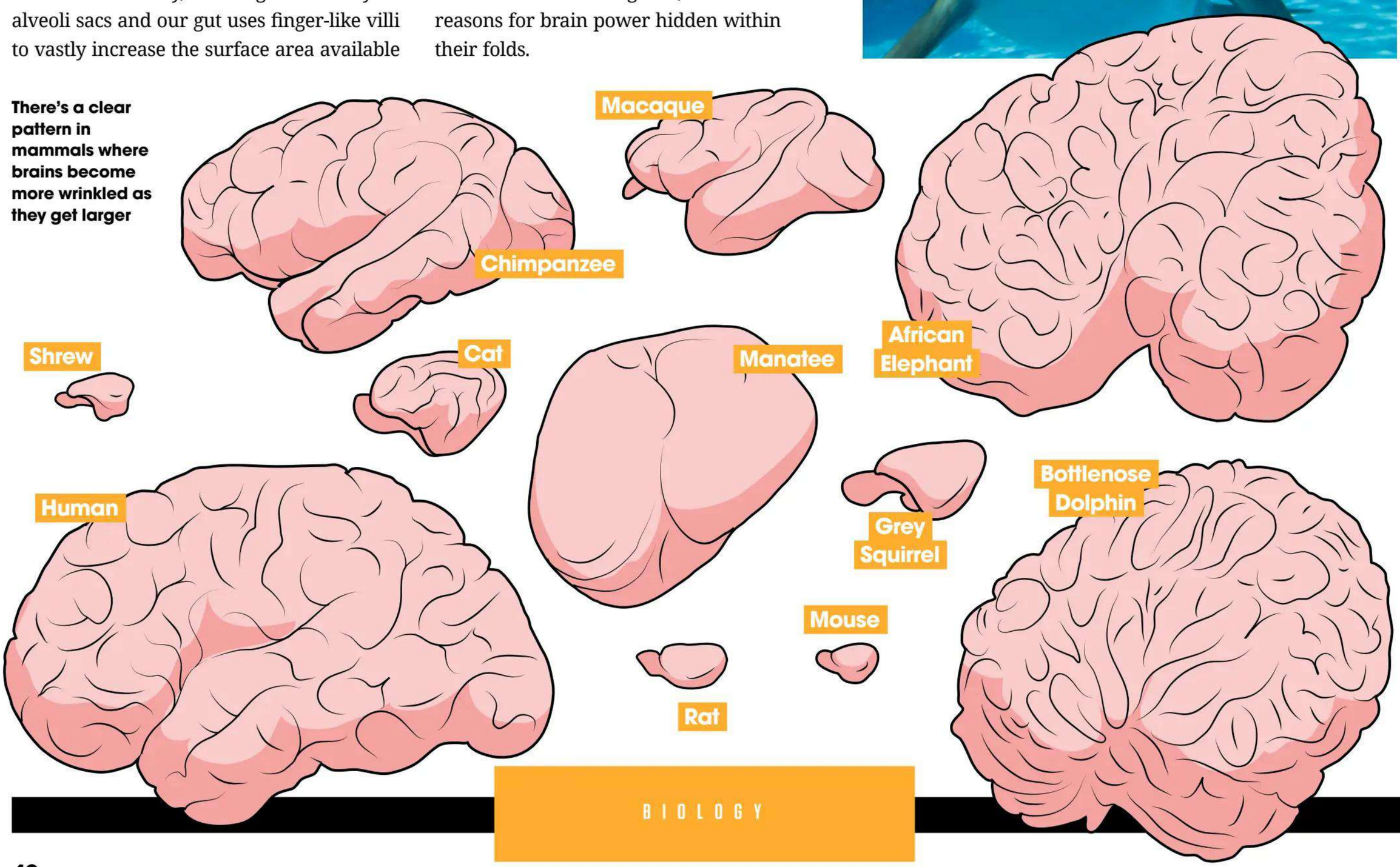
In humans, a condition called lissencephaly, which describes when the brain is smooth and not wrinkled, causes severe and fatal mental development issues. However other mammals, such as mice and marmoset monkeys, are naturally lissencephalic. Typically, mammalian brains become more wrinkled as the brain becomes larger, meaning that larger rodents and primates possess gyrencephalic brains. But humans have neither the largest or the most wrinkled mammalian brain. In fact, the Atlantic bottlenose dolphin has a brain about the same mass as a human's but is nearly twice as wrinkled.

Humans do, however, have thicker layers of the brain, which may help explain our higher intelligence. While wrinkly brains usually mean bigger brains and are correlated with intelligence, there are other reasons for brain power hidden within their folds.

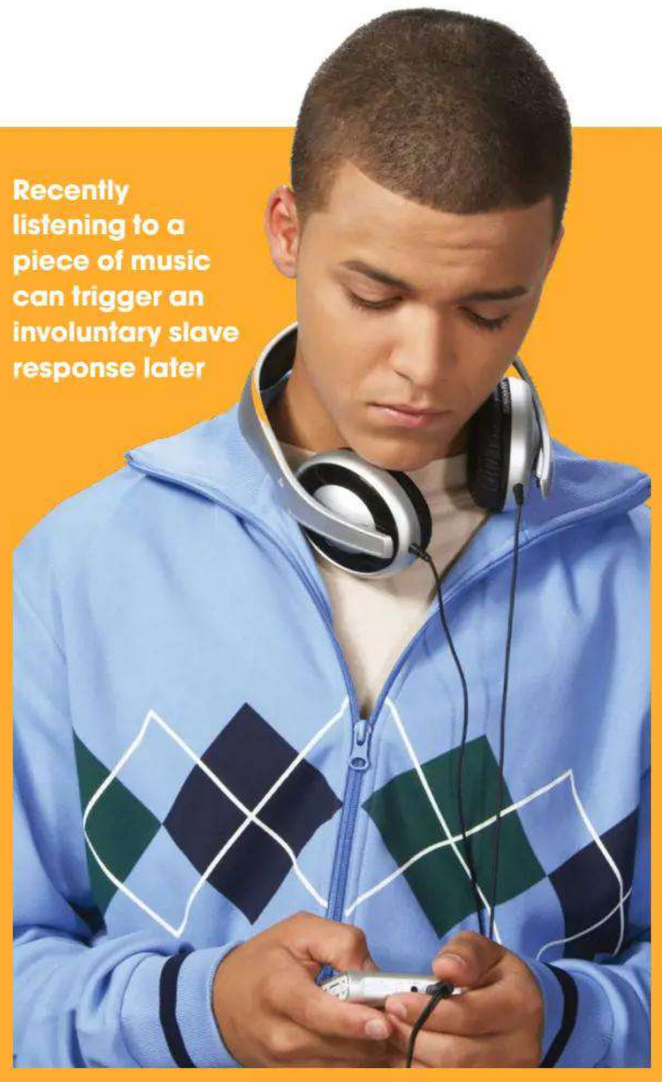
Mice can problem-solve



Dolphins are considered to be highly intelligent




There's a clear pattern in mammals where brains become more wrinkled as they get larger

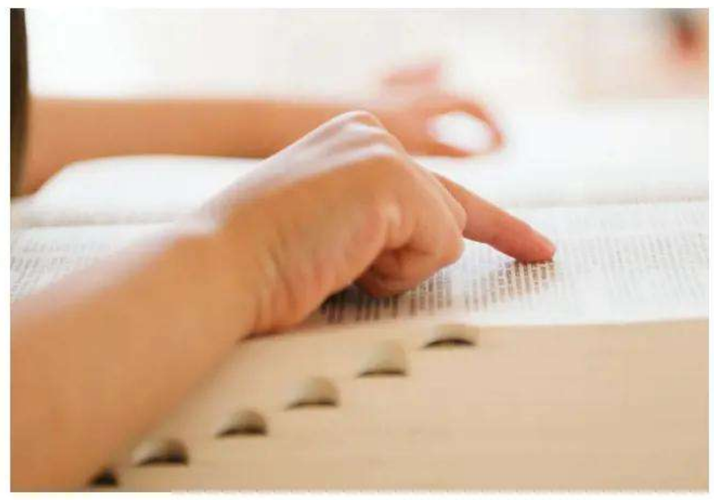


Recently listening to a piece of music can trigger an involuntary slave response later

## Earworms prove we're slaves to our brains

**3** Many functions controlled by the brain are autonomous and involuntary, such as breathing, digesting and shivering. But sometimes thoughts can be involuntary as well. One example of this is the 'earworm', where a song gets stuck in our head. In 1974, a research paper by Alan Baddeley and colleagues proposed the idea of 'working memory', which describes how we possess a small store of information that can be rapidly drawn upon to form decisions. In service of the working memory are the 'slave systems' which store audio-visual information and verbal information respectively. The verbal information slave system has a component known as the 'phonological loop' which can store short tracts of audio and rehearse them. This essentially builds an involuntary 'replay audio' button in our working memory. More recent research has additionally found that involuntary earworms can be triggered by recently listening to the offending piece of audio or by observing a different audio or visual cue that is associated with the memory of the song or sound. This means that a catchy song can be recalled and played on a loop entirely autonomously, even when we'd rather be rid of it.

# 4 Your brain is constantly trying to trick you with these weird phenomena



## LETHOLOGICA

In the middle of a conversation, our sentence stalls. We stop talking and search our brain for a word that isn't there. This is lethologica, when a word is at the tip of your tongue. We know what we want to say and know there's a word that fits, but we can't recall it because our memory has faltered. This is thought to happen more often with words that we don't use, because we haven't built strong recall connections with these words. Adults are believed to have an average of 50,000 words in their vocabulary, so lethologica could happen with many of them.

## Déjà VU

The sensation of déjà vu, French for 'already seen', describes times when we feel as if we've already experienced the present moment. For psychiatric patients déjà vu is often associated with anxiety, but around two-thirds of individuals also experience the sensation regularly. Déjà vu occurs when our brain makes a false familiarity with a new stimulus. This results in the construction of an artificial memory that triggers the sensation. Research suggests we're more likely to experience déjà vu when we go to new places and have new experiences.

## MISOPHONIA

Sufferers of misophonia are sensitive to certain sound patterns that others pay no heed to, causing symptoms such as anxiety or anger. The sound of chewing is a common culprit of this, but foot tapping or the sound of a clock ticking can also trigger a response. Strangely, patients have reported that the subtle nature of these stimuli is what makes them potently irritating. The cause of the condition is not currently fully understood, but there are certain parallels with triggers observed in sufferers of Tourette's syndrome and obsessive-compulsive disorder.

## THE DOORWAY EFFECT

It can be irritating when you walk into a room and forget the reason why you entered in the first place. It's a consequence of the way our brain assembles and maintains memory. When we walk through a door, our memory passes through what researchers term an 'event boundary', which is when the currently experienced 'event' is banked into long-term memory as the next event begins. However, not all the banked information is retained for immediate recall. This means that when we pass through the door and go through an event boundary, our reason for entering the room can be lost from our working memory

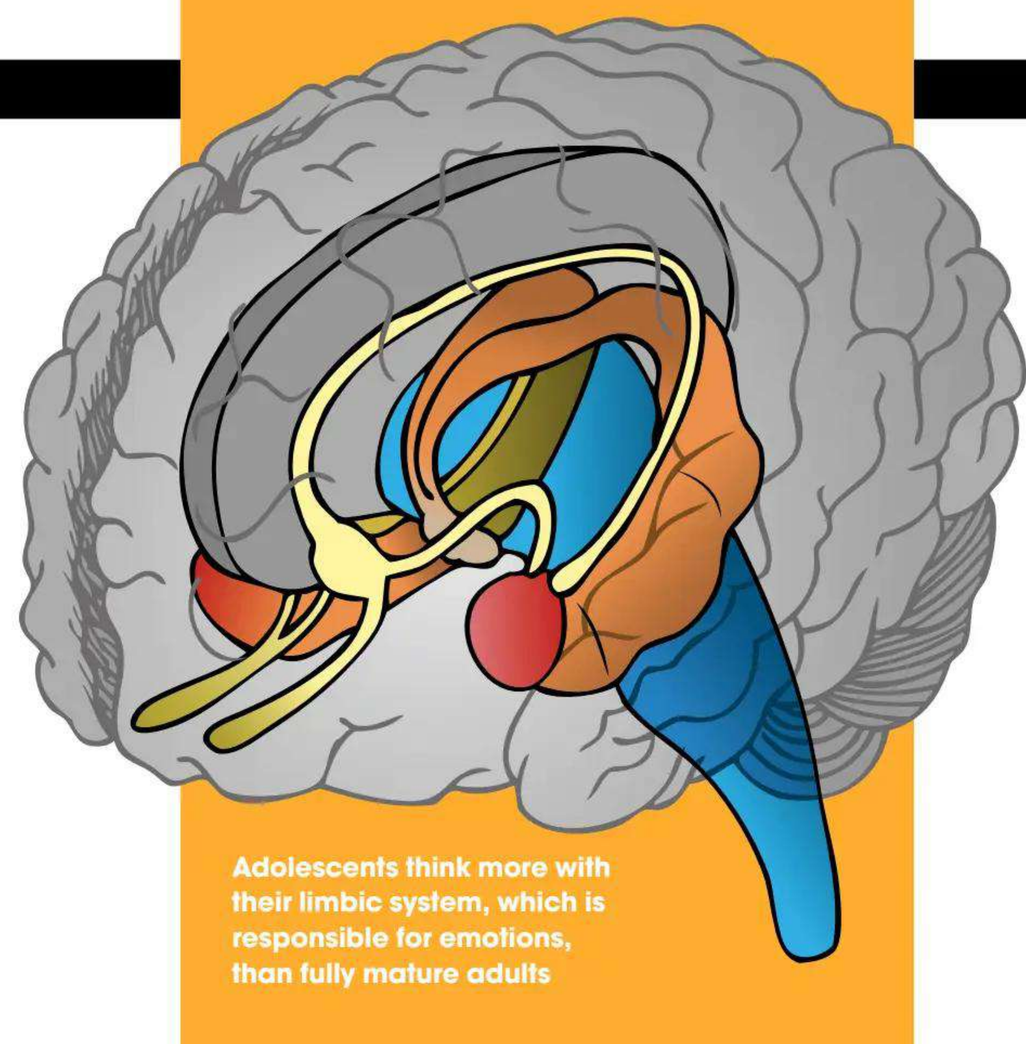
© Illustrations: Ed Crooks / Getty

# The brain is mostly water and fat

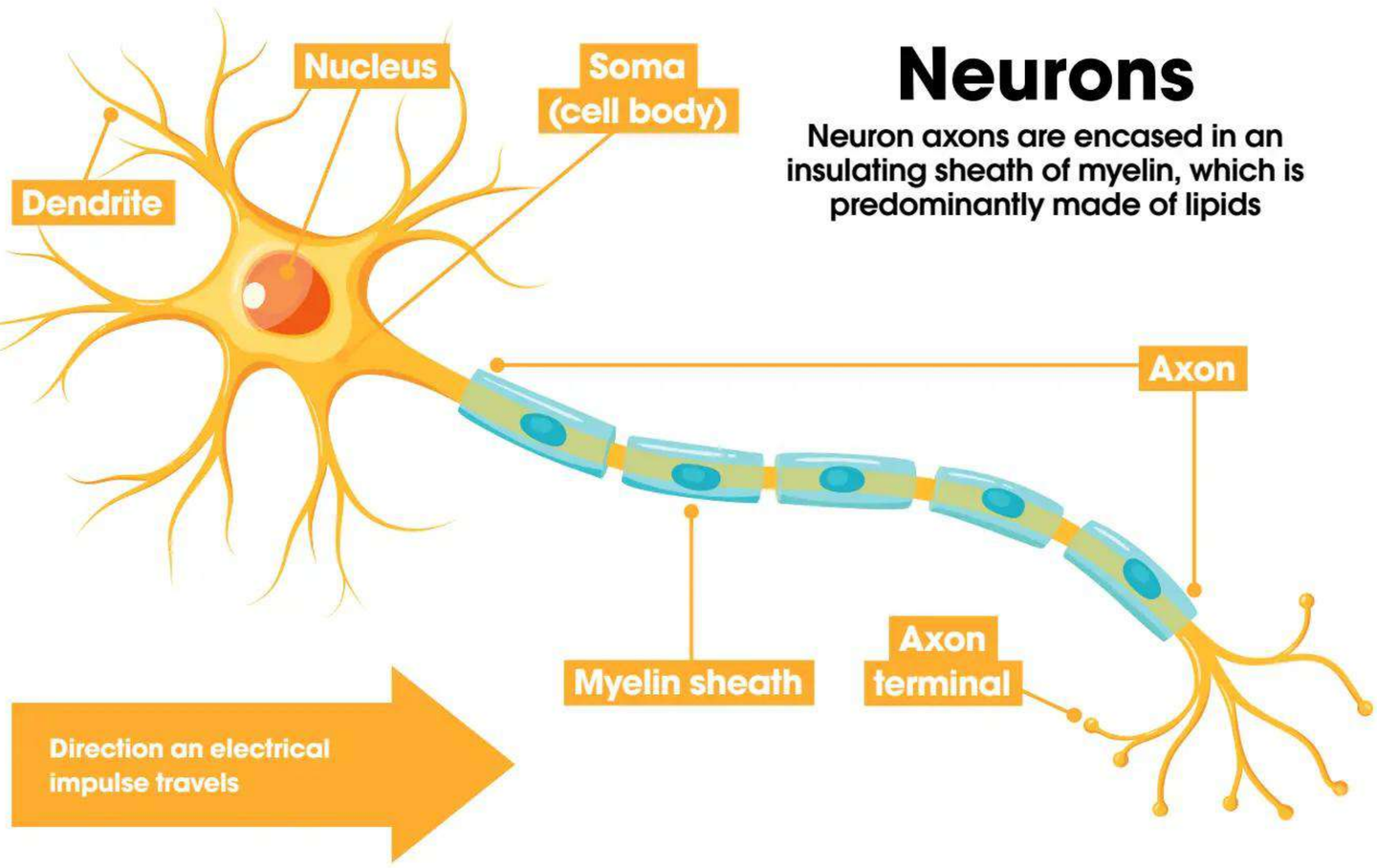
**5** Many organs of the human body are mostly water, and the brain is no different. The other compounds – including fats, proteins, carbohydrates and others – only make up about a quarter of our brain material. However, a brain's dry weight shows that fat is the dominant structural element of the brain. These aren't just the sorts of saturated fats you'd find in your favourite takeout or snack, but types of lipids, including cholesterol and fatty acids, that are used to form myelin.

Myelin is a structure made up of approximately 80 per cent lipids and 20 per cent protein and is found wrapped around parts of our brain cells, known as neurons. Neurons are composed of three main structural elements, including dendrites, which receive electrical signals from neighbouring cells. The cell body, also known as a soma, contains genetic information and provides the cell with energy. Axons carry electrical impulses away from the cell towards neighbouring neurons. Like electrical wiring in our homes, axons require an insulating sheath to protect the cell and ensure that the signal remains strong and moving in the desired direction. Myelin sheaths are used for this task, meaning neurons with long axons harbour a lot of fatty material.

The brain possesses a rich abundance of axons – so many that myelin-dense areas change the colour of the brain on scans, turning it white rather than grey. Grey matter, which is found around the periphery of the brain, is mostly composed of soma. Matter, however, consists mostly of axons and their fatty coatings of myelin. While the brain might be surprisingly fatty, without lipids it simply wouldn't be able to function.



Adolescents think more with their limbic system, which is responsible for emotions, than fully mature adults




## Neurons

Neuron axons are encased in an insulating sheath of myelin, which is predominantly made of lipids

## Composition

| ~76% | ~12% | ~8% | ~1% | ~2% | ~1% |
|---|---|---|---|---|---|
| Water | Lipids (fats) | Proteins | Carbohydrates | Soluble organic substances | Inorganic salts |

## Your brain isn't fully developed until you're 25

**6** Our brain reaches nearly full volume inside the cranium within the first few years of life, but the regions of the brain still require considerable development. These major regions are each associated with controlling certain behaviours and emotions, and throughout childhood and adolescence they develop at different rates, reaching maturity at different times. By the time we're 25, it's widely considered that all regions of the brain have reached maturity, but prior to this time we go through periods where the development is unbalanced, leading to different behavioural traits.

As the brain's grey matter develops from back to front, the prefrontal cortex at the top-front of the brain is one of the last regions to reach maturity. Unfortunately for parents wishing to reason with their teenage children, the prefrontal cortex is responsible for rational judgement and long-term planning. Instead, as the region has not yet fully developed, adolescents operate primarily at the behest of their limbic system, which is responsible for emotions. As a result of this, adolescents are prone to take more risks and tend to fixate more on the present moment – their emotions rule over rationality.

# The brain is mostly water and fat

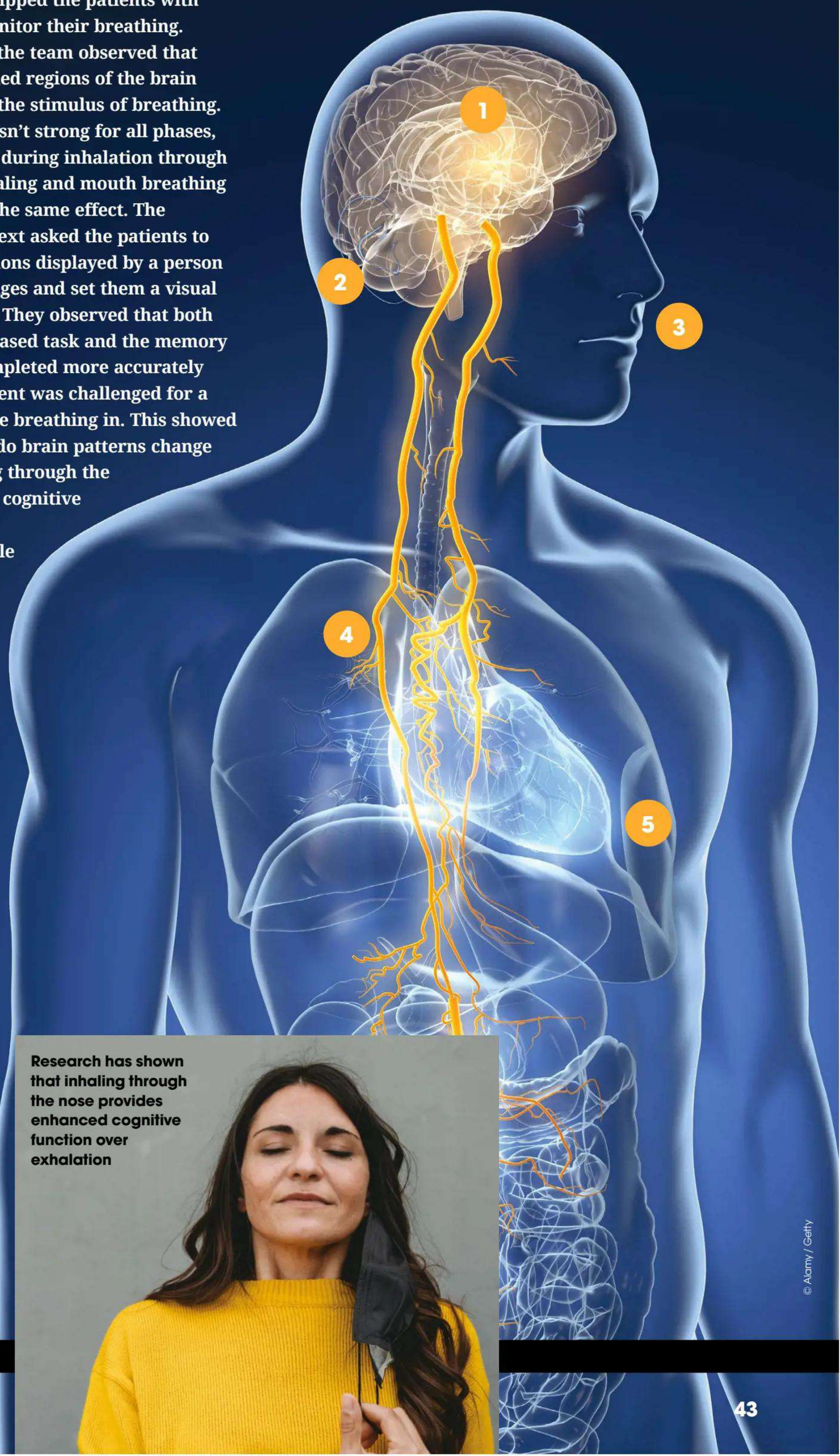
**7** It's long been understood that the brain regulates breathing. The brain stem, which sits at the base of the brain near the spine, regulates the autonomic nervous system that controls automatic functions such as heart rate, digestion and breathing. Less understood is that this process can operate as a feedback loop – breathing can also regulate brain activity.

In 2016, a team demonstrated this phenomenon by performing an experiment using epileptic patients prepped for surgery. They had already been fitted with electrode implants so that their surgeon could locate the origin of their seizures, allowing the researchers to accurately measure the activity of certain brain regions throughout the experiment. The regions of interest were those responsible for responding to olfactory nerves found up our nose (the piriform cortex), a region responsible for memory (the hippocampus) and a region responsible for emotion (the amygdala). The research team also equipped the patients with sensors to monitor their breathing.

Amazingly, the team observed that all three studied regions of the brain responded to the stimulus of breathing. This effect wasn't strong for all phases, but primarily during inhalation through the nose. Exhaling and mouth breathing did not have the same effect. The researchers next asked the patients to identify emotions displayed by a person using still images and set them a visual memory task. They observed that both the emotion-based task and the memory task were completed more accurately when the patient was challenged for a response while breathing in. This showed that not only do brain patterns change while inhaling through the nose, but that cognitive ability is also enhanced while breathing in relative to other states.

## Breathe deeply, think clearly

Taking five to ten breaths per minute can help calm your mind




**1 Triggering the amygdala**
When taking rapid, deep breaths, such as during periods of stress, regions of the brain associated with the fight-or- flight response are triggered.

**2 Triggering alpha waves**
During slow, deep breathing, regions of the brain associated with inward-directed thinking are triggered. These alpha-wave patterns are observed during meditation and promote feelings of calm and ease.

**3 In through the nose**
Olfactory neurons are stimulated mechanically as oxygen travels inwards through the nose, initiating a response in the brain.

**4 Vagus nerve feedback**
Slow, deep breaths trigger the vagus nerve to regulate the heart rate in tune with respiration. The nerve also relays information from the heart, lungs and gut back to the brain.

**5 Inhaling**
Inhaling reduces intrathoracic pressure, allowing blood to return to the heart faster, raising heart rate. The heart rate then slows during exhalation.

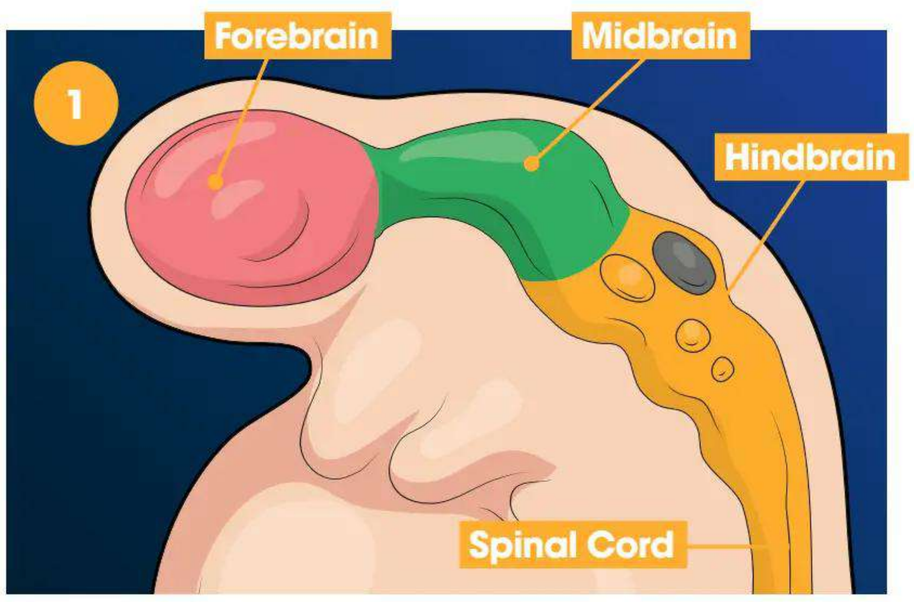
Research has shown that inhaling through the nose provides enhanced cognitive function over exhalation

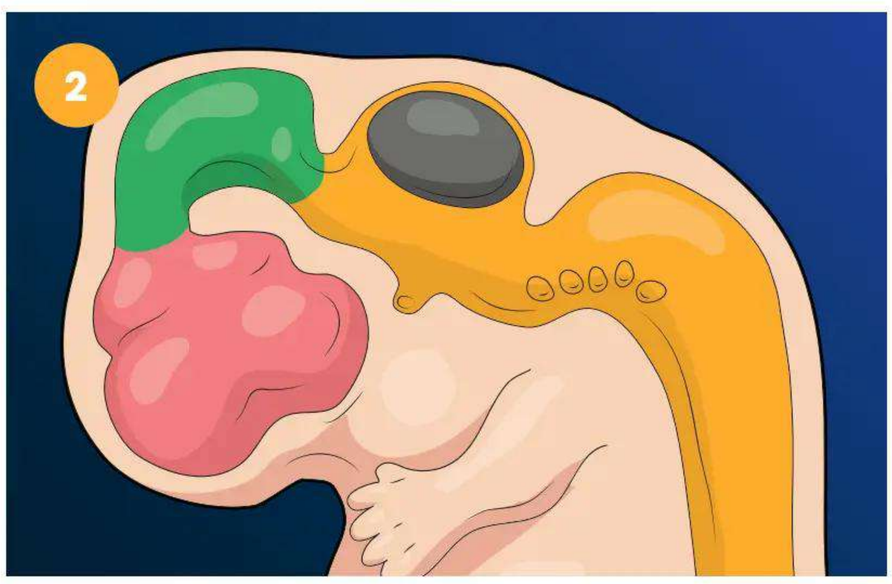
© Alamy / Getty

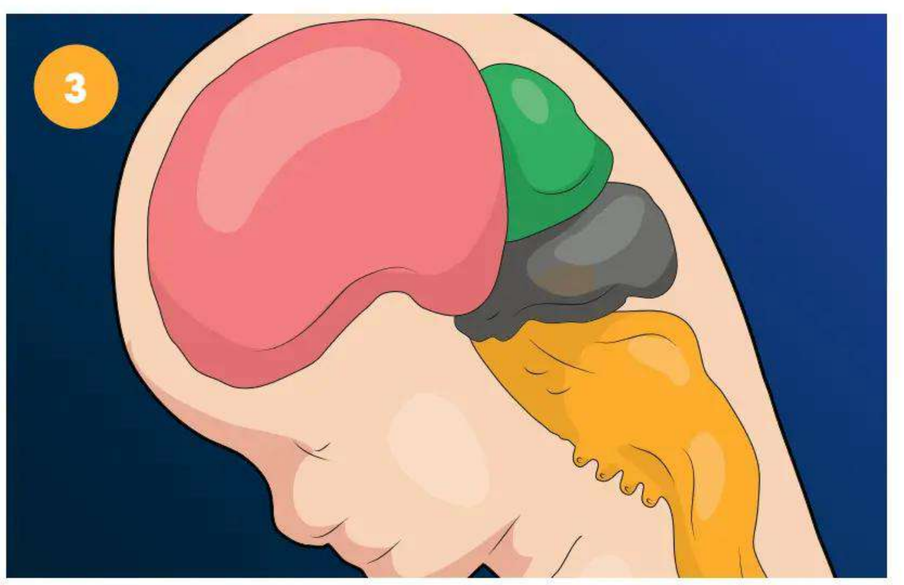
# Your brain begins as a tube

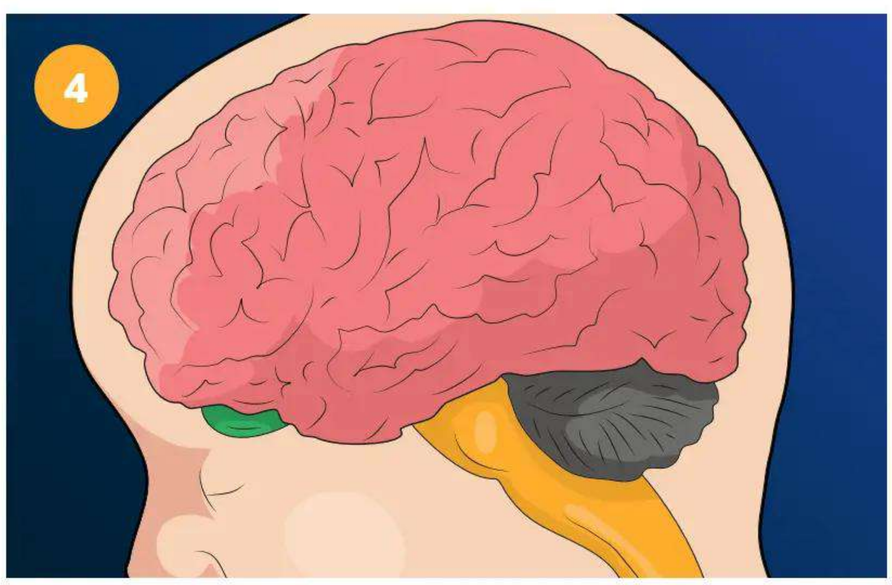
**8** Neural development begins very early in the growth of an embryo. The central nervous system begins its existence from one structure, starting as a sheet of cells known as the neural plate. A few weeks following conception, the neural plate begins to form ridges and folds in on itself, becoming a tube structure. From here the neural progenitor cells of the tube, which can differentiate and specialise into numerous brain cell types, begin to proliferate in a highly structured manner to mature the neural tube into the developed brain. The cavity inside the hollow tube remains, becoming a ventricular space that holds the cerebrospinal fluid that protects and nourishes the cells of the brain.

The expansive network of connections between neurons continues to develop throughout gestation as the brain grows, continuing long after birth. However, a foetus is capable of some cognitive function even during these early stages. By week 30 the pathways responsible for recognising pain are connected. While the foetus remains unconscious throughout most of its development, when awake it will eventually be able to recognise touch, smells, sounds and alter its facial expressions in response to these external stimuli. These responses are innate and non-conscious, but numerous studies have reported that babies can remember and recognise audio heard as a foetus from the womb, when the sounds were muffled and dampened but still audible. Newborn brains also come equipped with innate reflexes and behaviours to help the baby survive in the big wide world. Despite poor vision, they learn to recognise their mother's face almost immediately. They can determine the difference in touch between self and others and they can display emotions. It's just a slight shame that initially most of these displayed emotions often involve screaming and crying.




**1 3 weeks**
The budding brain starts off as the tip of a three-millimetre tube. This forms the beginnings of the forebrain, midbrain and hindbrain.

**2 7 weeks**
The regions continue to differentiate and expand. Buds of cranial nerves that will eventually connect the brain to the face, neck and torso begin to appear.

**3 11 weeks**
The rapidly growing forebrain becomes much larger than the other regions. At this stage, the forebrain is still smooth.

**4 Birth**
The forebrain expands and wrinkles, enveloping the midbrain. The hindbrain develops into the cerebellum and part of the brain stem.

## Reality-bending brain disorders

### Capgras delusion

Sufferers of this condition recognise their loved ones but do not believe them to be who they are. They become convinced that they've been replaced by imposters, robots or aliens. The condition has been seen in patients suffering from paranoid schizophrenia, dementia and brain injury.

### Alien hand syndrome

Also known as anarchic hand, patients with this condition lose full control of one of their hands, which periodically goes rogue. The rebellious hand appears to ignore orders from the brain and can reach, grasp and swipe. Patients can become convinced their hand belongs to someone else entirely.

### Foreign accent syndrome

Following a stroke that affects speech, a rare neurological condition can occur wherein the patient recovers their speech ability in a foreign accent. This can occur even if they've never visited the country.

### Cotard's syndrome

Sometimes referred to as walking corpse syndrome, sufferers of this affliction think that they are dead. This can follow a depressive episode where the person stops feeling pleasure and is overcome by feelings of worthlessness and can sometimes be treated with antidepressants.

# Stone-Age people conducted brain surgery successfully

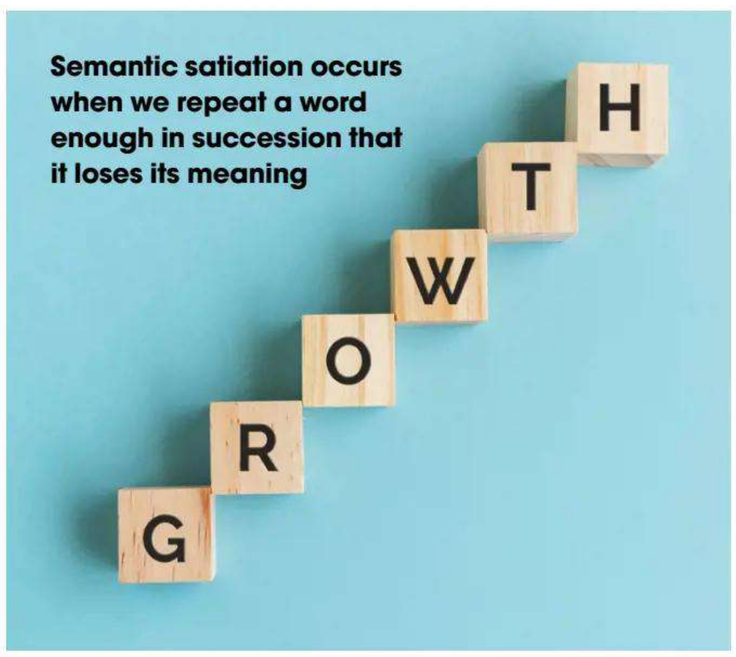
**9**

In 1996, a skeleton was unearthed from a Neolithic burial site in Alsace, France. The skeleton belonged to a man around 50 years of age who was believed to have died around 5000 BCE. Despite living 7,000 years ago, the man underwent surgery on his skull and survived for some time afterwards. The researchers who recovered his skull noticed that roughly circular pieces of it had been surgically removed in two places, which is known as trepanation. One segment was around 6.5 centimetres long, and the other around 9.5 centimetres long. While the reason for him undergoing these surgeries is unknown, other ancient cultures used trepanation as a treatment for ailments such as headaches, epilepsy and mental illnesses. The surgery carried numerous risks, including haemorrhage, brain damage and infection, yet the researchers determined that the man survived for at least a decent period after the procedures. The bone around one of the trepanation holes had partially healed, while the other had fully healed, sealing the hole completely.

**The process of trepanation was used in ancient times to treat numerous ailments, and over time the skull could heal**

**Trepanation has been practised across the ages in many cultures**

# If you repeat something enough, it loses meaning




**Semantic satiation occurs when we repeat a word enough in succession that it loses its meaning**

**10**

Words are the product of when our brains connect a particular sound to a specific meaning. Our brains are incredibly adept at maintaining this connection, providing us the power of language and the means to readily communicate complex ideas with another human that shares this knowledge. However, we can temporarily but rapidly sever the connection between sound and meaning, and we can do this simply by repeating a word. This effect is known as semantic satiation, where repetition strips a word of its meaning and renders it just a sound. You may have encountered this effect when vocalising a word over and over, perhaps when practising saying it or demonstrating its phonetics. Semantic satiation is believed to be caused by saturation of the brain with the same input, lessening the effect of the input to the point where it has no effect.

## 5 Brain Myths busted

### 1 Ten per cent

While neurons may be heavily outnumbered by other brain cells, we employ much more than ten per cent of our brain for almost all actions, even for simple ones such as gripping an item.

### 2 Male vs female

Males and females have historically been attributed to have different cognitive abilities for certain tasks, but recent studies show this isn't the case. For example, a study looking at maths ability in children from 68 countries found no differences between the two sexes.

### 3 Teach an old dog new tricks

While people may become unwilling to learn new skills when they grow older, the neurons in their brains are still able to form new connections, so they remain able to learn, permitting the desire is there.

### 4 Bigger than our ancestors

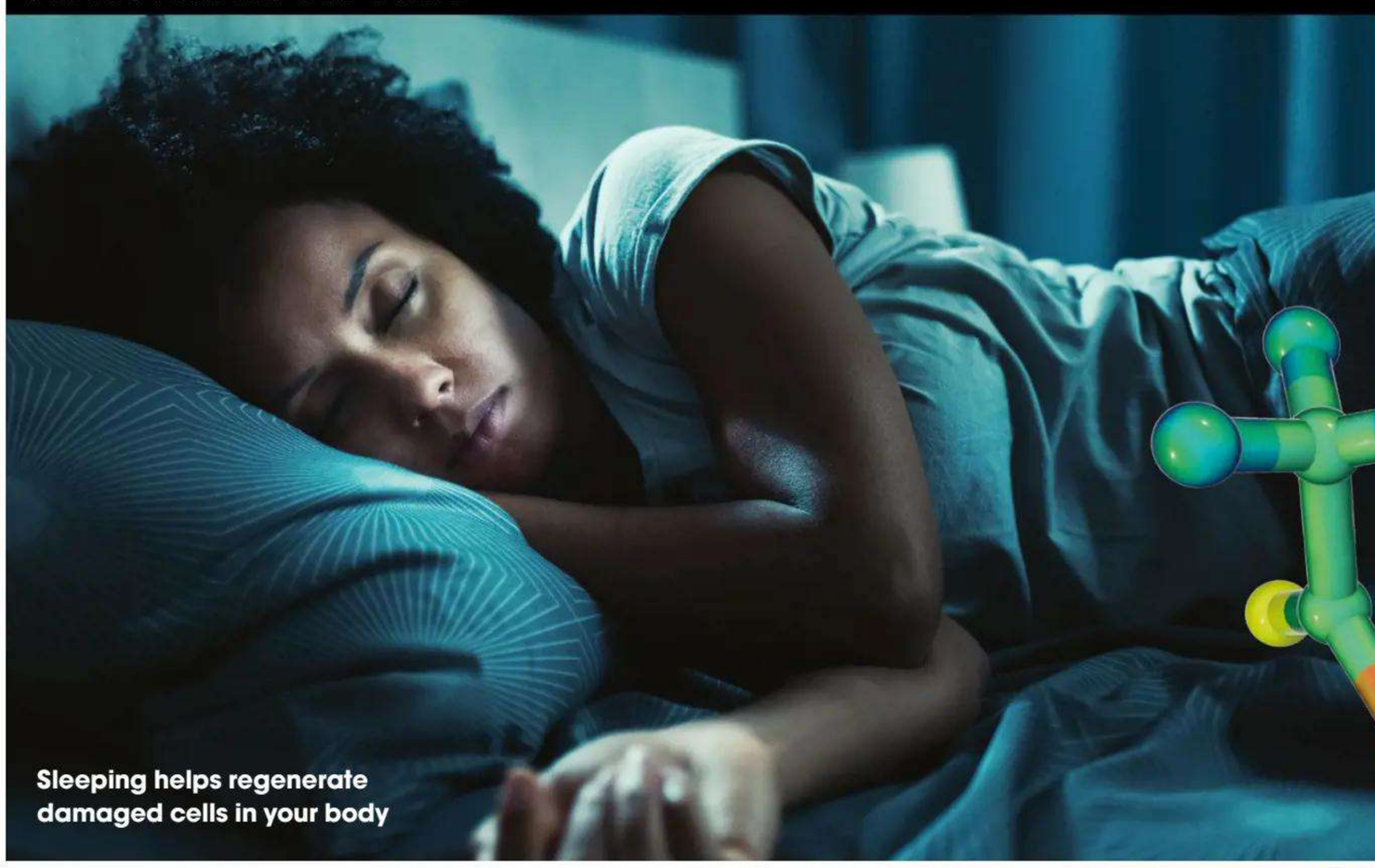
We may feel smarter than any humans who came before us, but counterintuitively our brains are around ten per cent smaller than our ancestors' from several millennia ago.

### 5 Brain fog isn't real

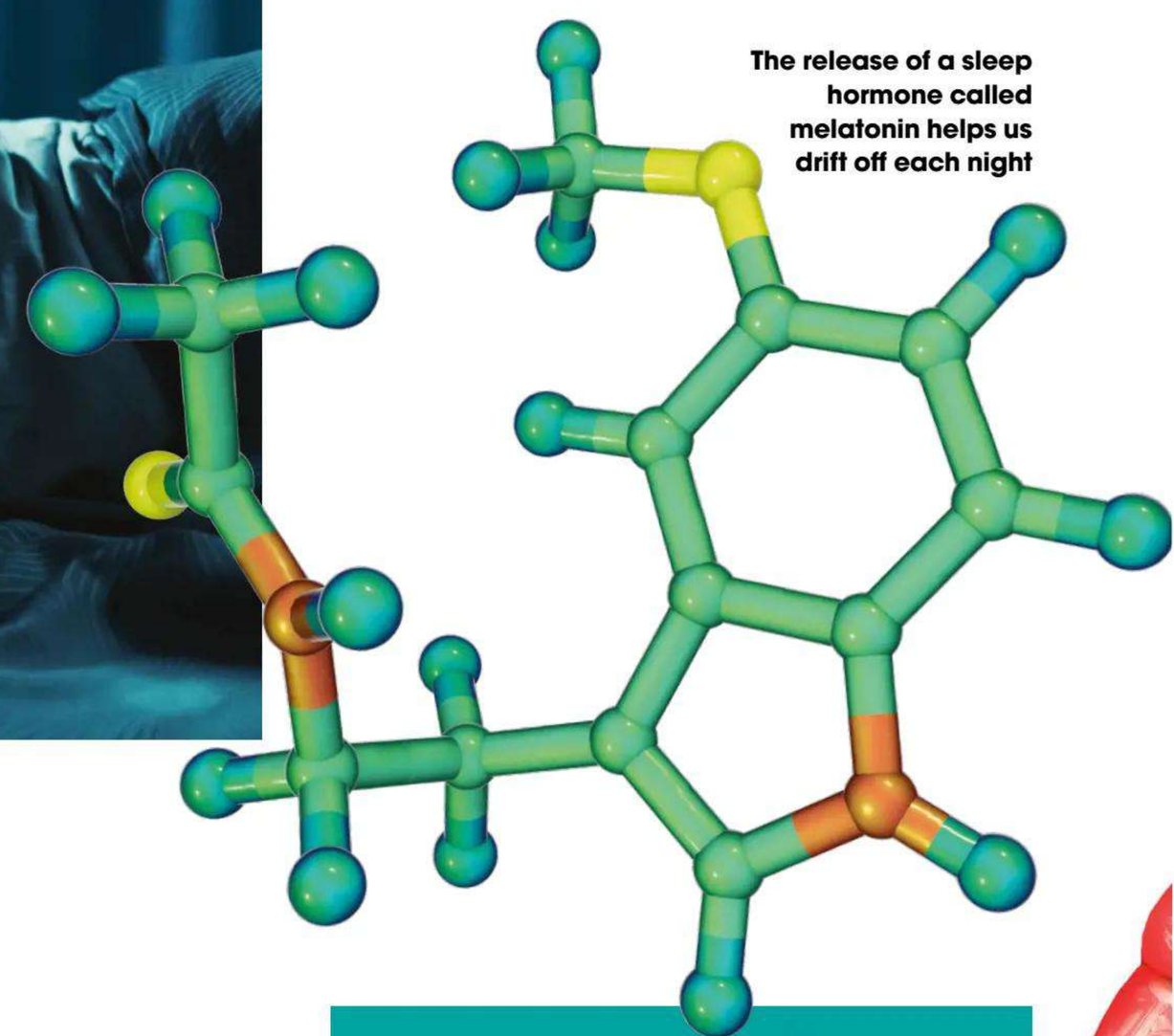
Although it isn't a medical term, brain fog describes when the brain's usual clarity is lacking, causing forgetfulness, confusion and slower mental processing.

© Illustration: Ed Crooks / Getty / Wellcome Images

Sleep



Sleeping helps regenerate damaged cells in your body



The release of a sleep hormone called melatonin helps us drift off each night

# Why do we sleep?

*The science behind your body's ability to power down at night*

Humans spend about a third of their entire lives asleep, but scientists still aren't entirely sure why. The human body is governed by a 24-hour sleep-wake cycle known as circadian rhythm. This internal clock coordinates the body's physical and mental systems as the body transitions from alertness to sleep. It does this by responding to the changes in natural light in your environment. As natural light dims and night falls, the circadian rhythm kicks the body's melatonin production into gear. Melatonin is a hormone that helps the body enter the sleep portion of the sleep-wake cycle. And humans aren't alone in having an internal body clock – countless species, including plants, fish and insects, all experience their own circadian rhythm.

Once we're asleep, our body goes through four to six sleep cycles and experiences physical changes in temperature, heart rate and brain activity. It's also a regenerative time for the body. During sleep, many different growth hormones are released to repair and replace any cells that have been damaged or that have died.

Sleep has also been linked with immune system support and the consolidation of memories. Some studies have even shown that sleep helps the brain flush out some toxins that build up inside it during the daytime.

A lack of sleep can prove fatal. A series of rodent studies conducted in the late 1980s revealed the negative impacts of sleep deprivation. Researchers discovered that all study rats that had been completely deprived of sleep died or were "sacrificed when death seemed imminent" between 11 and 32 days. All other basic needs, such as food and water, were met, and no other physical causes of death were identified. The benefits of getting a good night's sleep are abundant, but the answer to why we and the majority of other animals on Earth evolved wake-sleep cycles remains unclear. Some evolutionary theories suggest that sleep may be a survival function to keep animals out of harm's way during the night, conserve energy and reduce competition for resources.

## The longest sleeper

Snoozing more than any other animal on Earth is the koala, which clocks up to 22 hours of sleep per day and uses the remaining few hours to eat eucalyptus leaves. The reason these nocturnal feeders spend so much time asleep is because of their diet. The typically toxic leaves of the eucalyptus tree contain cyanide-like compounds that are fatal for some, but not koalas. Koalas are able to break down the toxic compounds among the 500 grams of leaves they consume per day. However, this comes at a cost. Metabolising the toxic eucalyptus leaves takes up a lot of energy, and they're also very low in nutrients. It makes you wonder why they love to eat them so much.

Koalas snooze away the majority of their day

# Inside the sleeping mind

What parts of the brain are involved with sending us to sleep?

**Basal forebrain**

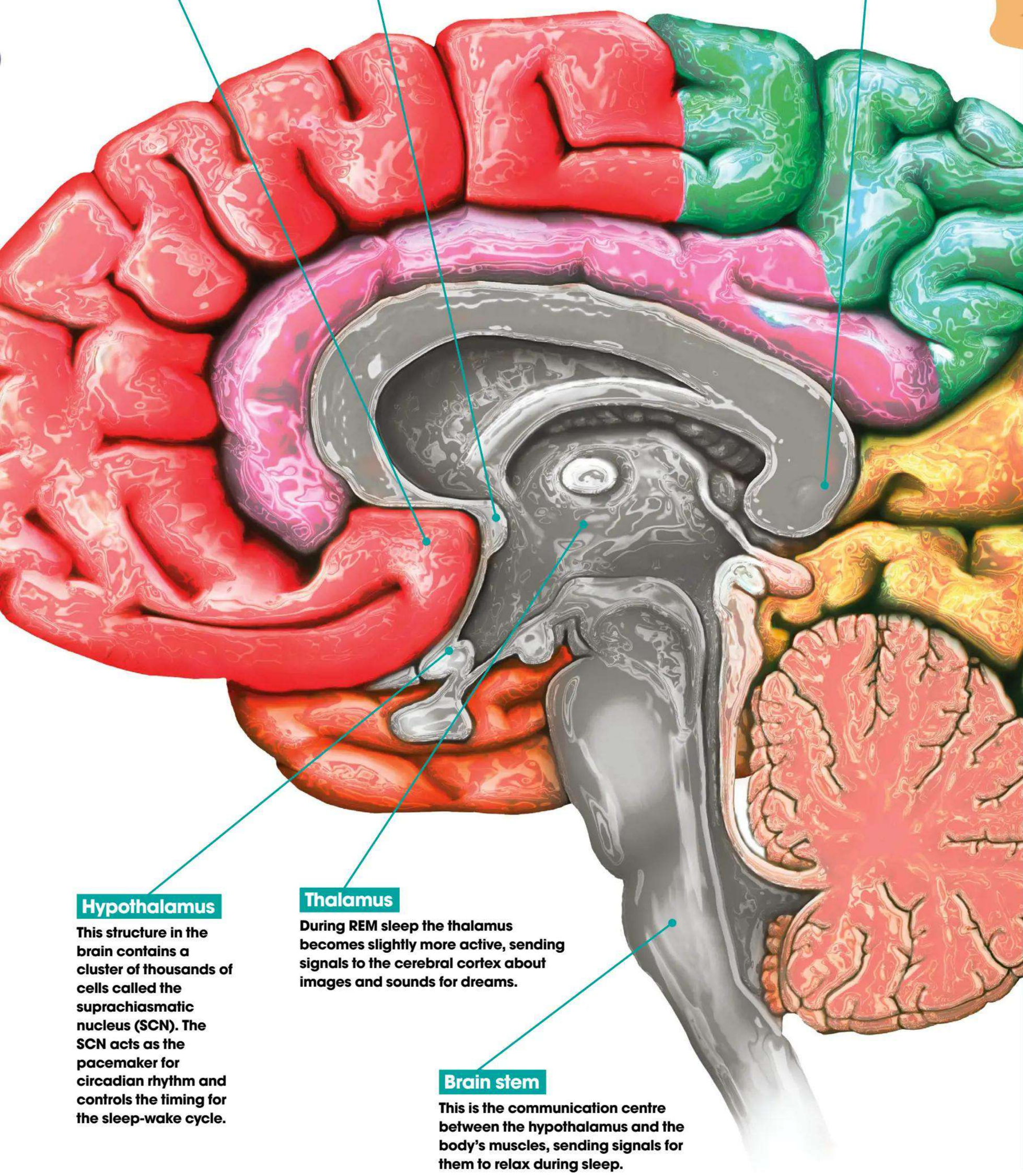
Cells in the basal forebrain release a chemical called adenosine that increases a person's need for sleep, known as a sleep drive.

**Amygdala**

An almond-shaped portion of the brain that provides the emotional content of dreams during REM sleep.

**Pineal gland**

The SCN signals the pineal gland to produce melatonin to induce sleeping. This typically occurs in the absence of natural light.



**Hypothalamus**

This structure in the brain contains a cluster of thousands of cells called the suprachiasmatic nucleus (SCN). The SCN acts as the pacemaker for circadian rhythm and controls the timing for the sleep-wake cycle.

**Thalamus**

During REM sleep the thalamus becomes slightly more active, sending signals to the cerebral cortex about images and sounds for dreams.

**Brain stem**

This is the communication centre between the hypothalamus and the body's muscles, sending signals for them to relax during sleep.

## The four stages of sleep

### 1 non-rapid eye movement (NREM)

The initial transition from consciousness to unconsciousness. During this light sleep stage, muscles relax and heart rate slows down along with breathing and brain waves. This stage can last for up to five minutes.

### 2 Second NREM

Over the next hour or so, sleepers enter a deeper stage in the sleep cycle. Heart rate and breathing patterns are reduced, along with the body's temperature. During this stage, eye movements also cease.

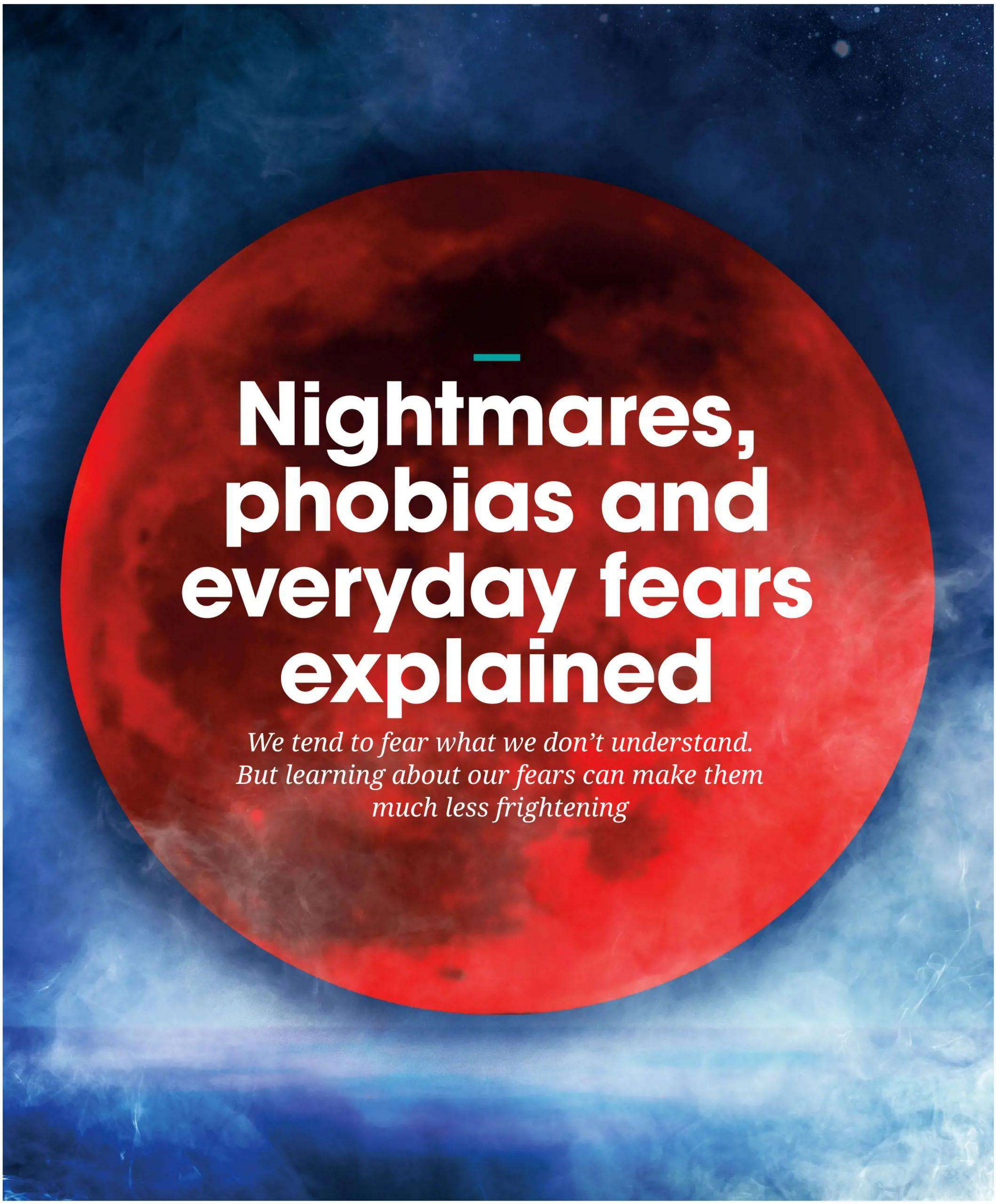
### 3 Third NREM

The deepest sleep stage, all vital signs reach their lowest levels and the muscles are fully relaxed. This stage typically lasts for up to 40 minutes. It's believed that this is the most restorative stage in the sleep cycle.

### 4 Rapid eye movement (REM)

Brain activity picks up during this stage, but the muscles enter atonia, or temporary paralysis. The eyes also enter a state of rapid movement beneath the eyelids. This is the stage where dreaming typically occurs.

© Getty

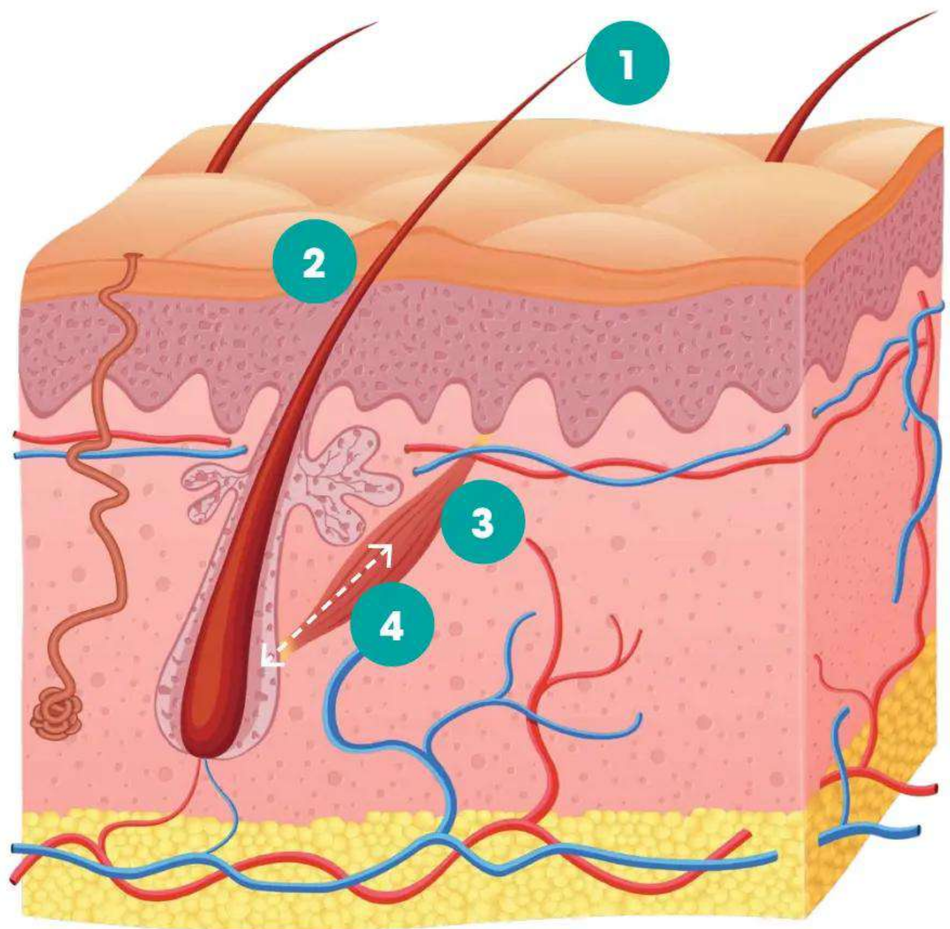


# Nightmares, phobias and everyday fears explained

*We tend to fear what we don't understand. But learning about our fears can make them much less frightening*

# Why do we get goosebumps when we're scared?

Sitting at home, alone and in the dark, a sudden sense of fear and a swift chill may wash over your body. Sure enough, your hairs stand to attention and goosebumps cover your skin. It's a sensation we've all felt at one time or another, but why does our body react in this way when we're scared? It harkens back to a time when ancient humans faced the daily fear of life-threatening predators. As a result our bodies evolved what we now call a fight-or-flight response. This is a stress response which triggers a release of adrenaline, causing our heart race to rush, our palms to sweat and goosebumps to appear. During this state of fight or flight, the tiny muscles adjacent to each hair contract, making hairs stand on end. Today humans are relatively hairless compared to our animal ancestors. Charles Darwin postulated that at one point in time our ancestors would have been a great deal hairier, and goosebumps would have puffed out their hair to make them look bigger and appear more intimidating to potential predators.

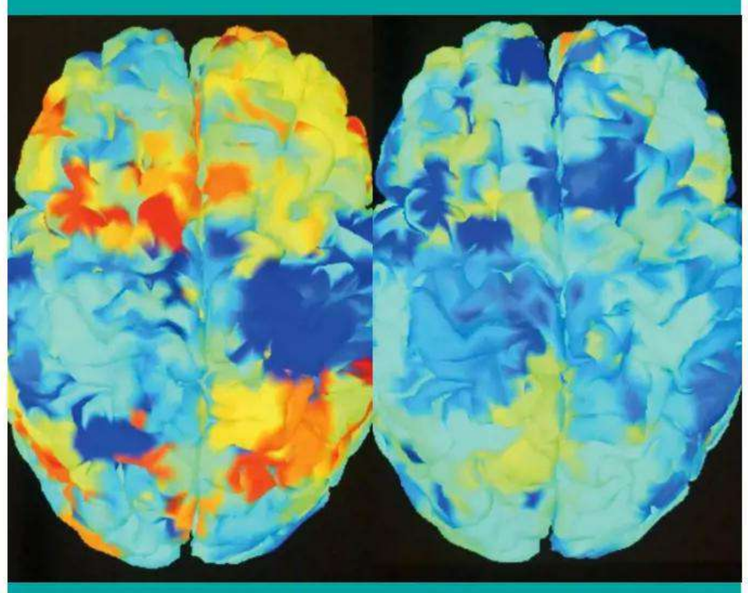



**1 Hair**
There are about 5 million hair follicles across the human body, equipped with muscles called arrector pili muscles.

**2 Goosebump**
During the contraction of arrector pili muscles, the skin puckers like a plucked chicken, forming a goosebump.

**3 Contraction**
Adrenaline release makes these muscles contract, pulling the base of the follicles and making hairs stand on end.

**4 Relaxed**
Tiny muscles attached to the base of the hair follicle are normally relaxed, allowing the hair to naturally lay on the skin.



Brain patterns were observed using a functional magnetic resonance imaging (fMRI) machine

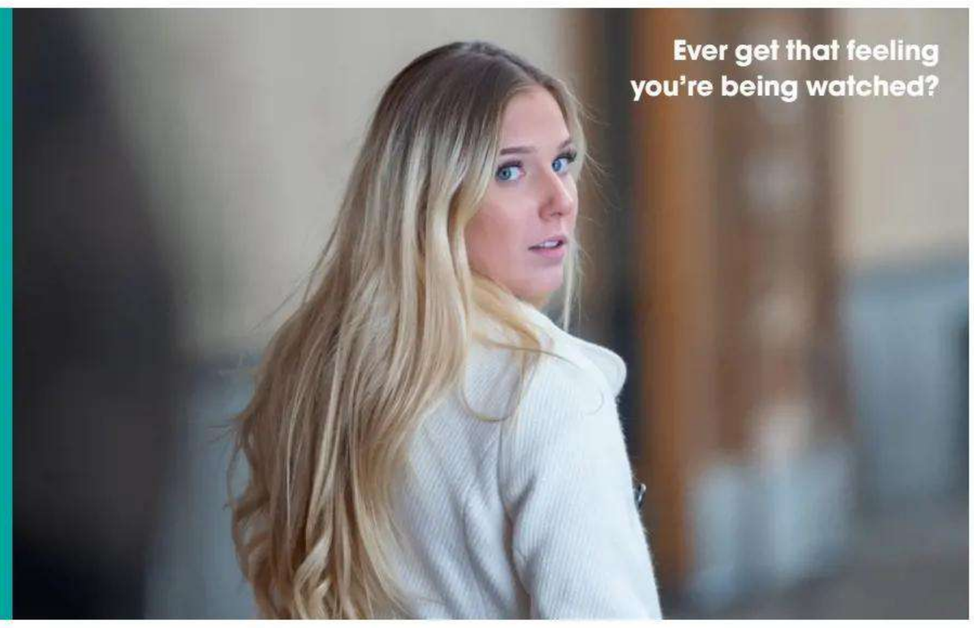
## Is mind-reading possible?

Our thoughts are our most private and personal belongings, and the idea that someone could go snooping around inside our heads is terrifying. However, the technology to do so is being developed. Besides the moral and ethical hurdles of mind-reading, the brain is an extremely complex organ. Taking it one step at a time, researchers have been analysing the electrical patterns we produce in the brain when we think of something, such as an object, number or even a sentence. The researchers can then identify and decipher distinct patterns associated with those thoughts in the hope of building a neural dictionary of patterns.

The technology is still in its relative infancy, with years of development needed before complex thoughts can be interpreted. Currently this is being developed to offer insights into the way our brains work, rather than for alternative medical treatments. However, the potential of mind-reading technology is wide-reaching. From understanding autism to predicting a person's decision-making, once you can peer inside the mind, the possibilities are endless.

## How do you know when someone is watching you?

Do you ever get a nagging feeling that someone is staring at you? Is it really possible for us to have a six sense of when we're being watched? Studies have found that a single brain cell fires signals when someone looks at us, stopping when their gaze moves away. This was put to the test in 2013 on a patient with cortical blindness. The patient's visual cortex in the brain was damaged, but the brain still received information from the eyes. What was interesting was that the region of the brain that responds to potential threats, called the amygdala, became active when someone stared at the patient. This innate six sense most likely evolved in ancestral humans as a way to detect when a predator was nearby, giving them the chance to escape.



Ever get that feeling you're being watched?

© Getty

# Why do we have nightmares?

Typically people dream for around two hours a night. During this portion of rest, called rapid eye movement (REM) sleep, is when nightmares can creep in. Sometimes referred to as 'threat rehearsal', it's believed that nightmares occur to prepare us for the possible dangers we might face in real life, although many nightmares are stress-related. At some point during human evolution nightmares may have served a purpose in bringing real-world dangers to our attention and keeping us alert to potential threats. However, in a world where we're no longer chased by prehistoric predators or battling the elements, do nightmares still have a role to play?

Although the dangers that may have birthed this neurological function are long forgotten, modern threats such as house fires, car crashes and murder keep nightmares alive. There is, however, a way to battle against them before you head to bed. Some suggest rehearsing an alternative ending to any recurring nightmares while awake, and trying to understand any reasons behind your nightmares is paramount.

Losing your teeth is one of the most common nightmares

## Inside the nightmare

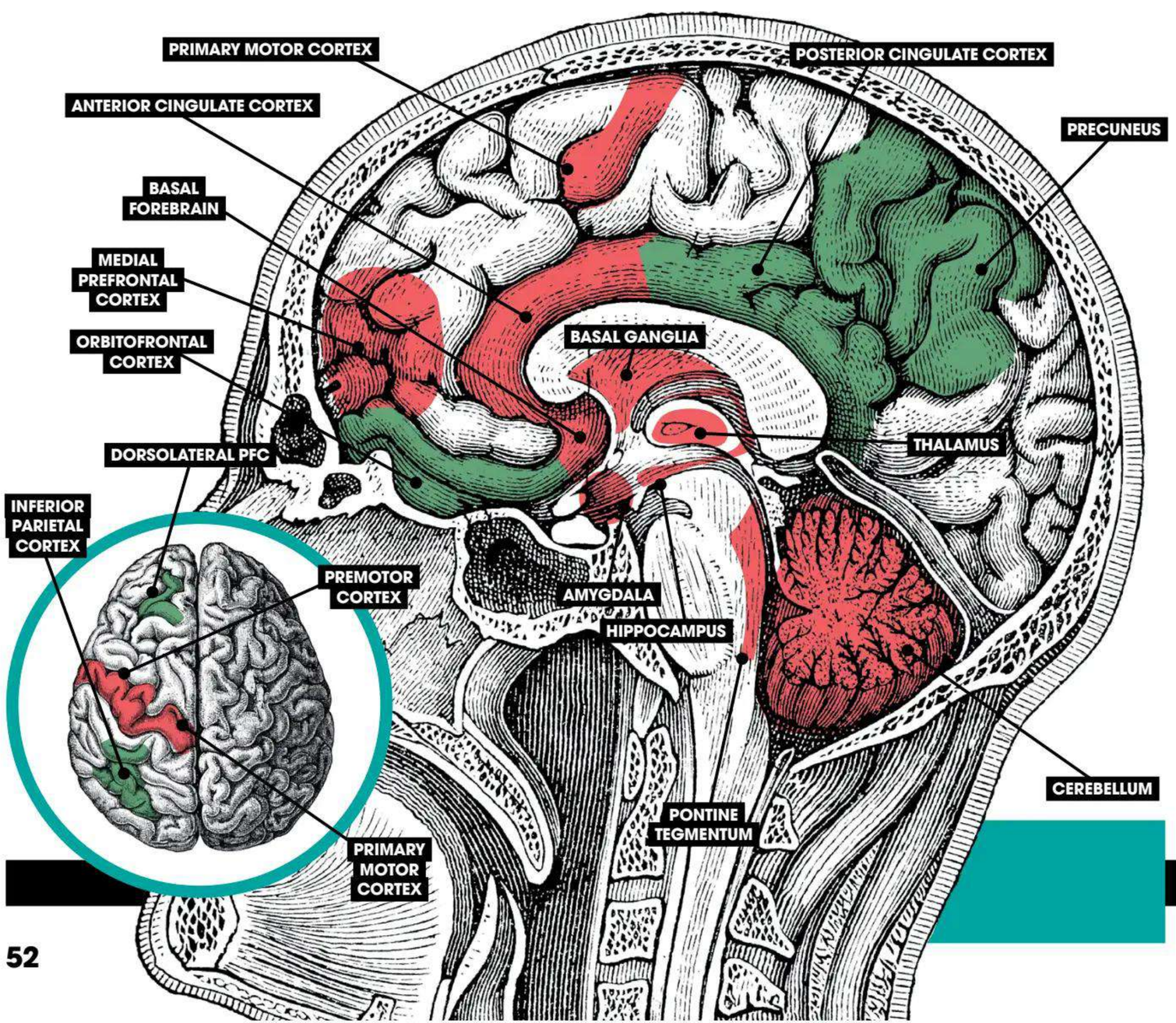
What regions of the brain are awake while we dream?

### Activated

**Several regions of the brain active during REM sleep that have different roles when considering their functions while dreaming. Regions like the cerebellum, basal ganglia and premotor cortex are linked with the motor content of our dreams. They are responsible for creating the sensation of movement, like running from an intruder during a nightmare. Others, such as the thalamus and basal forebrain are linked to emotion-processing aspects of our dreams.**

### Deactivated

**While many regions are activated to produce dreams and nightmares, some are deactivated to allow them to occur. Regions of the prefrontal cortex and inferior parietal cortex are typically involved in cognitive control, perception of time and space, and self awareness. This allows us to drift off into a dream unaware of our physical bodies. The deactivation of these regions is thought to contribute to the reason we don't often remember our dreams when we wake up.**



A squat lobster found in th e Mariana Trench, the deepest part the ocean

## What is lurking at the bottom of the ocean?

Fewer people have seen the deepest parts of our oceans than have walked on the Moon, so our knowledge of what swims in the deep blue is relatively small. The deepest region of the ocean is called the hadal zone, which begins around six kilometres below the surface. This largely unexplored region consists of trenches formed by Earth's tectonic plates and is inhabited by marine life that can withstand its extreme pressures and lack of sunlight. Some crustaceans and even species of fish, such as the hadal snailfish, have been observed in the zone as deep as eight kilometres below the surface.

## What causes a blood moon?

Every year or so our lunar neighbour rises in the sky with an eerie crimson glow, known as a blood Moon. It's a phenomenon that typically happens around May, and occurs during a lunar eclipse. This is similar to a solar eclipse, whereby the Moon and Sun perfectly align, blocking our view of the Sun. During a lunar eclipse, however, it is Earth that is blocking most sunlight from the Moon. Any light that does make it to the surface of the Moon passes through Earth's atmosphere. As the visible spectrum of light travels through our atmosphere, blue wavelengths are scattered, leaving red wavelengths to journey to the Moon and giving it a reddish hue. Throughout the year there are other occasions when the Moon appears ruddy, and they're often mistaken for a true blood Moon – this is due to pollution, cloud cover or debris in the atmosphere.

## Inside the venom

How black widow venom causes excruciating pain

**Venom gland**

Venom is produced and stored in a small sack at the front of the spider's head.

**Alpha-latrotoxin**

As the main culprit for the causing of pain, this chemical embeds itself into the membrane of our nerve cells.

**Open the gates**

The calcium in our bodies is needed to help generate communication between our nerves. However, alpha-Latrotoxin opens all gates to flood the cells with calcium.

**Communication**

The presence of calcium in the nerve cells triggers neurotransmitters to cross the junction between nerves and opens gates on another nerve for sodium to pass through. This is how nerve cells talk to one another and send signals to the brain.

**Pain**

With an increase in activity within the nerve cells, the brain perceives these signals as pain. The more signals produced by the flooding of calcium and sodium, the more pain you feel.

**Venom canal**

When the spider is threatened the venom will travel from the venom gland, down the venom canal and into the fang, passing into its victim.

**Overload**

Now flooded with calcium, the nerve releases an increased amount of neurotransmitters in the junction between nerves, which then creates a signal in the adjacent nerve.

# Why is black widow spider venom so potent?

Striking fear into the hearts of those that spot the tiny red markings on an otherwise ordinary-looking spider, black widows are some of the most venomous creatures on Earth. This accolade has led to many people believing this spider to be an aggressive insect. In reality these spiders are shy and they only attack humans when their bodies have been pinched or they're accidentally squashed.

However, when they do strike it wreaks havoc on the human nervous system. What makes their bite so agonising is the presence of a neurotoxin called alpha-latrotoxin. This neural hijacker causes rampant pain throughout the victim's nervous system. However, it's a common misconception that a single bite from a black widow spider is always a death sentence. Fatality is rare in healthy humans, with most recovering with medical assistance in 24 hours. Young children and those who are ill or elderly are at the highest risk.

**"In reality these spiders are shy"**

Black widows are found in temperate regions around the world

© Alamy / Getty / Illustration by Nicholas Forder

# Inside a serpent jaw

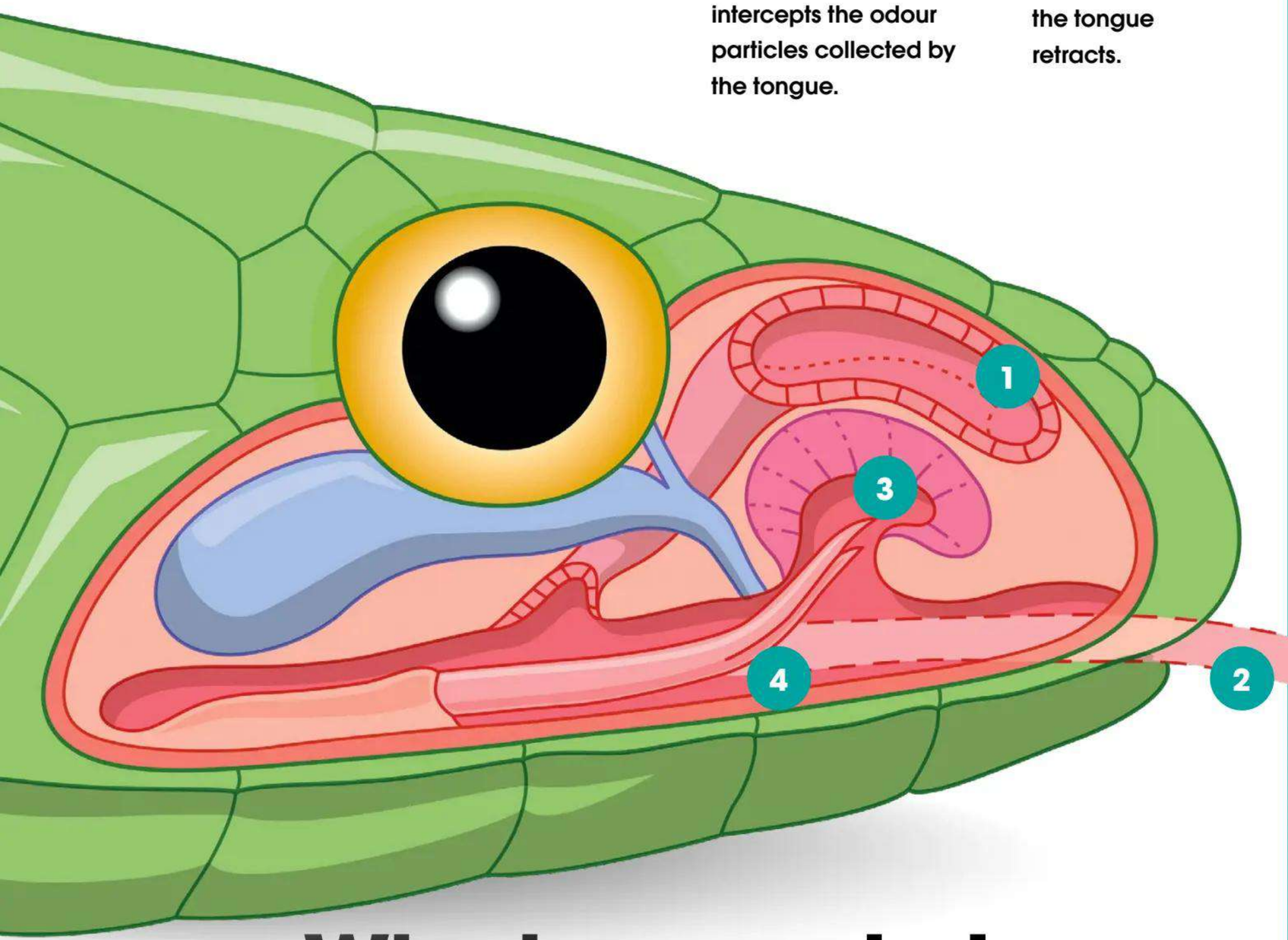
What's lurking behind a snake's fangs?

**1 Nostril**
Unlike humans, a snake's nostrils are only present to allow them to breathe, lacking any ability to smell.

**2 Tongue**
Tiny odour particles from the atmosphere are collected by the snake's forked tongue while it flicks it in the air.

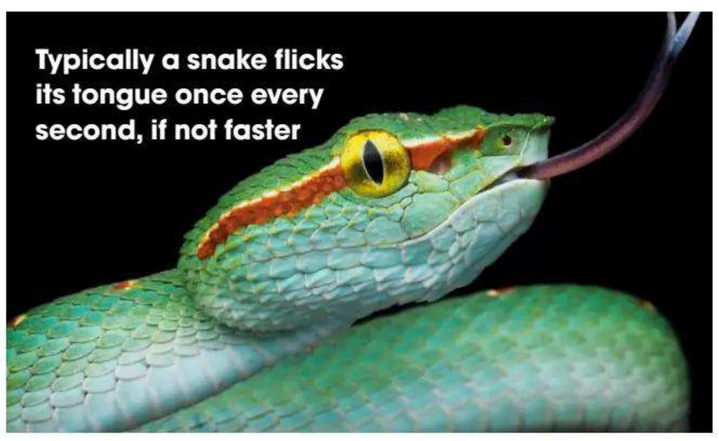
**3 Vomeronasal organ**
This chemoreceptive organ is connected to the olfactory bulb in the snake's brain, which then intercepts the odour particles collected by the tongue.

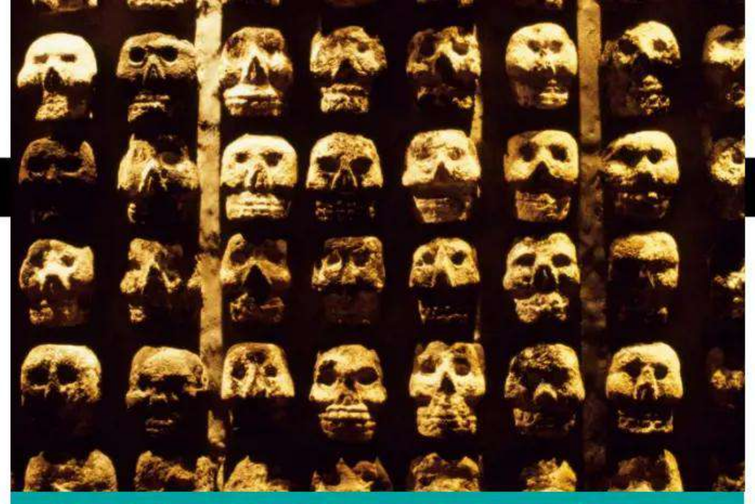
**4 Retraction**
Odour particles are mixed with the fluids inside the snake's mouth as the tongue retracts.




# Why is a snake's tongue forked?

It's all to do with the way these reptiles observe the world around them. The flicking of a serpent's forked tongue might seem intimidating at times, but they are simply tasting the air. While we use our noses to smell and our tongues to taste, snakes gather chemicals that pertain to smell and taste from the atmosphere and interpret them. Unlike the human tongue, snakes lack the many taste buds we've come to rely on. They have instead evolved a sensory organ called the vomeronasal, or Jacobson's organ, to detect moisture-borne odour particles. This has two holes – corresponding perfectly with the forked ends of the tongue – which collect the particles and deliver them to the vomeronasal organ as the snake flicks its tongue. The reason snakes do this is to detect the location of any potential prey, catching the scent of a nearby mouse in the wind or even the presence of a predator or potential mate.


Typically a snake flicks its tongue once every second, if not faster


The skull rack found during the excavations of the Aztec Templo Mayor, Tenochtitlan

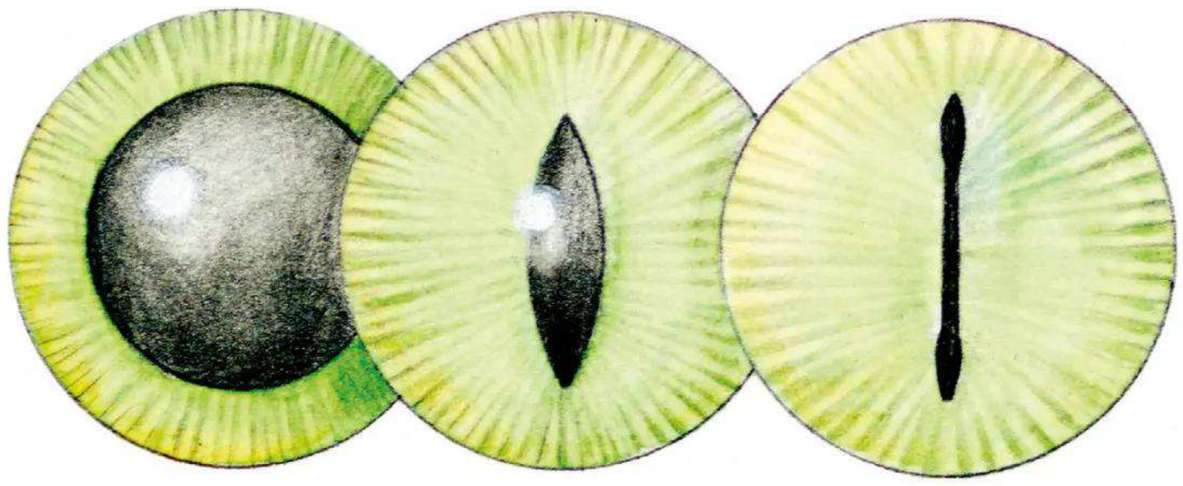
## Why did the Aztecs sacrifice humans?

Standing over a stone altar at a temple summit, an Aztec priest raises his obsidian blade before plunging it into the chest of the body before him, allowing the blood of the human sacrifice to cascade down the temple steps. It's a scene well documented throughout history when you delve into the traditions and rituals of the Aztecs, who lived between the 14th and 16th century.

Many Spanish conquistadors recorded seeing such bloodthirsty rituals, and even detailed a rack of 130,000 skulls of the victims called a tzompantli. It wasn't until 2015 that this enormous and terrifying edifice was excavated by archaeologists, revealing the secrets of human sacrifice. People were offered as nourishment to the Aztec gods to ensure that the Sun would rise and to allow prosperity for the people. Those that evaded the sacrificial altar were not the only ones thought to prosper from sacrifice. Those that felt the sharp edge of the knife were believed to gain an honoured place in the afterlife.

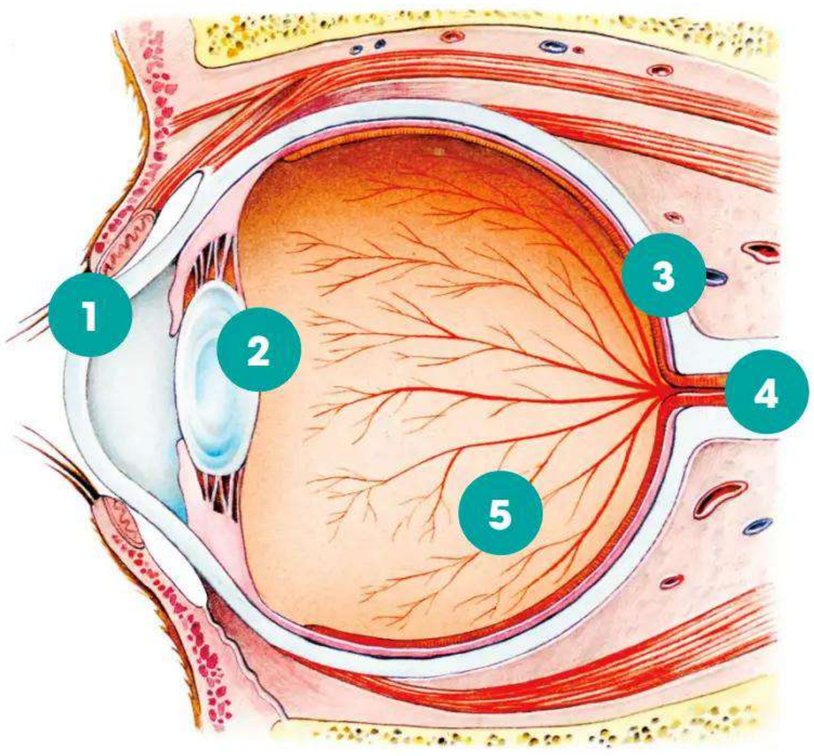
## Is your phone eavesdropping on you?

It seems oddly serendipitous when, after a conversation, online ads begin recommending brands of products you may have discussed. Is it a coincidence, or is your phone secretly listening to you? Facebook has repeatedly stated that its app does not listen to users for ad-targeting, though some sources report that many apps have permission to activate our microphones and the ability to analyse snippets of audio. In the grand scheme of things, however, listening in on our conversations for targeted ads isn't the most effective method to get relevant information – especially when you consider the wealth of information our digital footprints can provide, such as what we view, like or share on social media, or the cookies gained from our Google search history. It's far more likely that your previous online activities, a tweet or Facebook post has sparked an ad.



# Why are cat pupils vertical?

As fierce hunters, cats and other nocturnal predators have evolved vertically slit pupils as a way to better ambush their prey at night. To successfully seek out their prey, cats need to be excellent at gauging the depth and distance of their next meal. This is where having a vertical pupil comes in handy. Researchers have found that predators such as snakes, cats and crocodiles are better at depth perception and can easily focus on their targets.




## Look inside the eye

**Cats are among the sharpest-eyed mammals**

**1 Cornea**
The dome at the front surface of the eye that offers protection and lets light pass into the eye.

**2 Lens**
The lens changes shape to focus light into the retina.

**3 Retina**
Within the retina are cells that can detect light, called photoreceptors, which are split into two groups called cones and rods for binocular vision and collecting dim light.

**4 Optic nerve**
Light and image information is sent to the brain via a bundle of nerve fibres, collectively called the optic nerve.

**5 Vitreous chamber**
A gel-like-fluid-filled chamber maintains the shape of the eye.

## Will the Sun engulf Earth?

As our Sun expands towards the end of its life, the planets in its path will ultimately meet their doom. Earth is in the firing line, but not for a long time. In around 5 billion years the Sun will start to swell into a red giant, engulfing Mercury and Venus, then Earth. However, long before it swallows our planet, the heat generated from the giant fireball will boil the oceans and kill all life on Earth. In around 7.5 billion years the Sun will have used up 33 per cent of its current mass, weakening its gravitational hold on Earth and sending our planet into an expanded orbit. This may not be enough to save Earth, with many physicists predicting it will meet the same fate as Mercury and Venus.

# Is spontaneous human combustion possible?

The idea of spontaneously erupting into flames without any prior warning is a harrowing concept, but it's unsubstantiated by science. As a prevalent theme in fiction during the 1800s, novels such as Charles Dickens' Bleak House brought forth the terrifying idea that at any time one of us might suddenly ignite and perish.

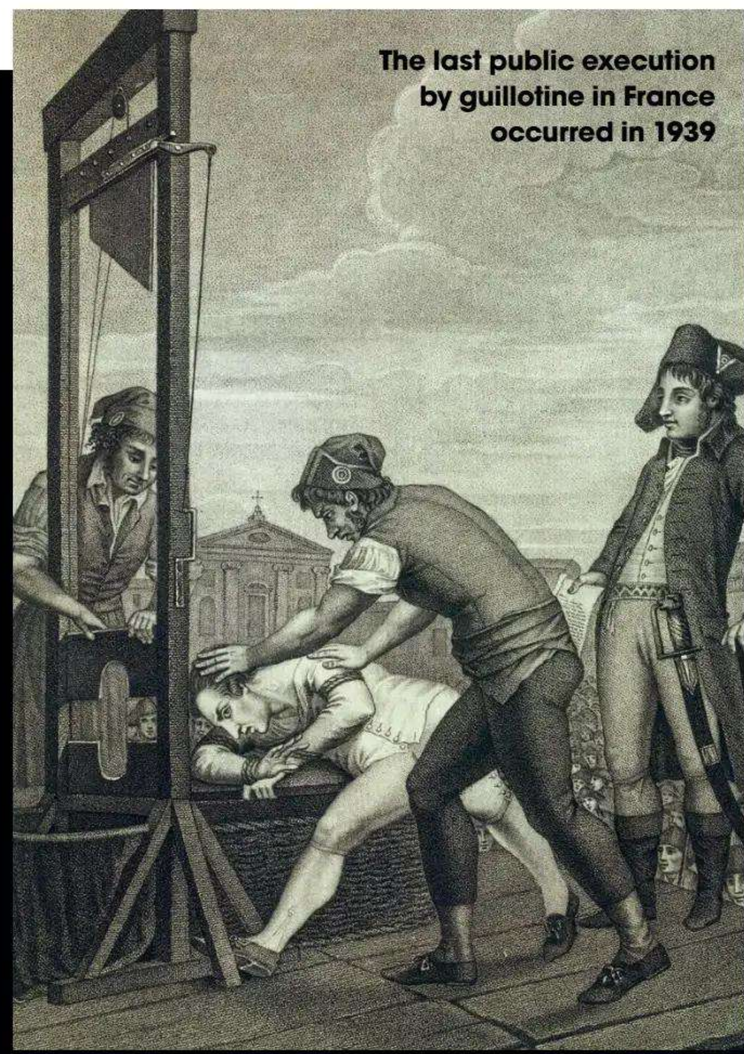
Following this idea were claims of real-life occurrences. However, only a handful have ever been formally investigated. Each incident involved elderly victims whose remains were found near open flames such as candles or smoking cigarettes. The fatal flaw in the idea of spontaneous human combustion is in our biology. The human body is made up of 60 to 70 per cent water, a natural enemy of fire. If an internal fire should ignite, our bodies would extinguish it.

# What is dark matter?

Looking out into the abyss of space might leave you wondering why the universe is dominated by darkness. It's believed that the universe is made up of roughly 80 per cent dark matter, a mysterious material which does not emit energy or light.

Although we aren't sure what it is made of, leading the pack as a potential candidate are weakly interacting massive particles (WIMPs), which have a hundred times the mass of a proton but are extremely difficult to detect.

© Getty / Alamy



The last public execution by guillotine in France occurred in 1939

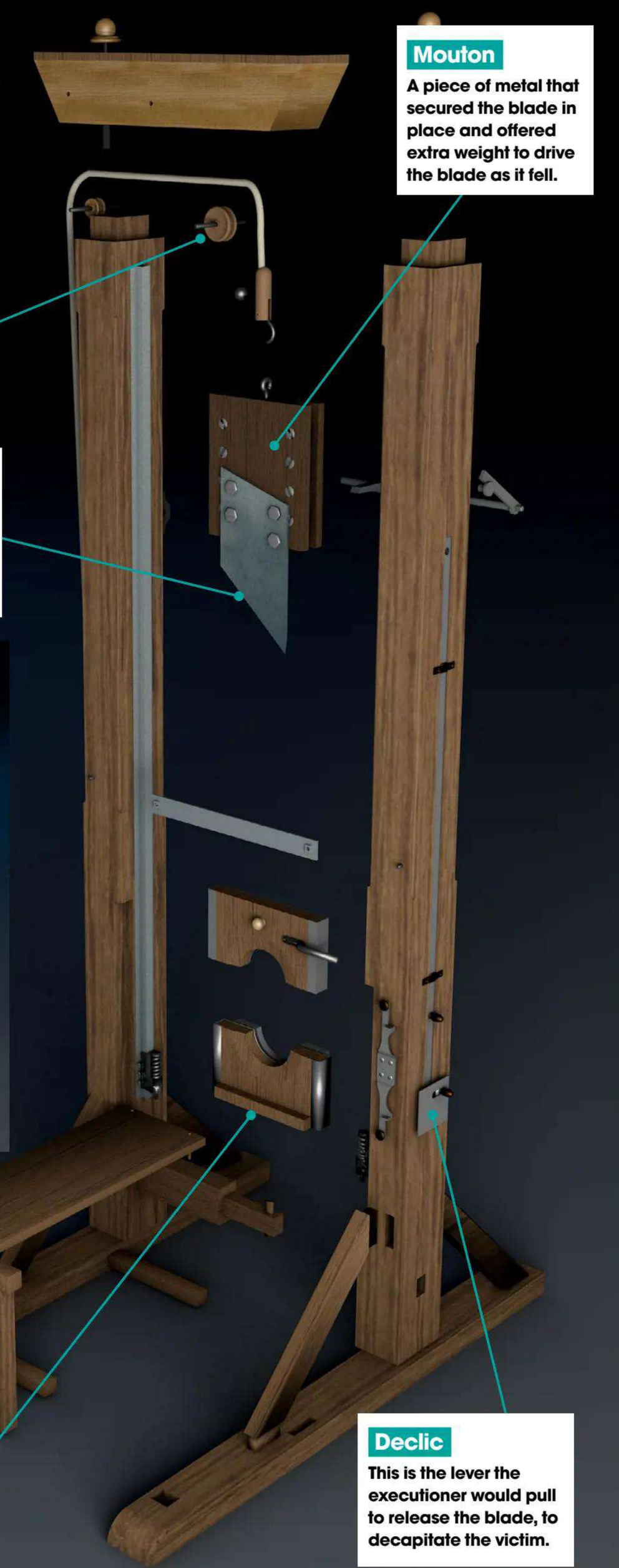
# Who invented the guillotine?

It may surprise you to discover that anatomy professor Joseph-Ignace Guillotin proposed the guillotine as a gentler method of execution. Guillotin believed that swift decapitation by a blade would be more humane than a sword or axe swung by an executioner. The first life to be officially claimed by a prototype guillotine occurred in France in 1792, designed by French doctor Antoine Louis.

This new form of execution was given the name guillotine after Guillotin's recommendation. However, it's believed that he was against capital punishment and was horrified by the device's name. The guillotine was used until 1981 when the death penalty was abolished, during which time it became a major spectator event and was deemed high entertainment, with souvenirs sold at executions and programmes listing the names of those being executed that day. The guillotine even became a popular children's toy, while novelty devices were sold as vegetable and bread slicers.

## Behind the blades

How does a guillotine work?



**Wheels**
Between the rope and the wooden frame, a series of wheels allowed the executioner to release and raise the blade.

**Blade**
Made from steel, the angular blade had serrated edges. Together with the mouton, it weighed around 40 kilograms.

**Mouton**
A piece of metal that secured the blade in place and offered extra weight to drive the blade as it fell.

**Restraint**
The victim was held between two wooden slats, called a lunette, to secure the head in place.

**Declic**
This is the lever the executioner would pull to release the blade, to decapitate the victim.

Could there be someone with the same face as you?

# Is someone out there wearing your face?

With over 7 billion people on the planet, there is surely going to be someone that shares enough of our facial features to be deemed our doppelganger. We seem to have an odd fascination with finding them and alerting others to their existence: "I saw your double in the supermarket the other day." However, the chances of actually finding one are relatively slim. A 2015 study found that there is a one in 135 chance that someone shares enough facial features to be deemed a doppelgänger. The figure was calculated by comparing eight distinct facial features of 4,000 different people. Researchers found that finding a doppelganger with all eight matching features was a one in a trillion chance.

## Could a scream be heard in space?

In the vast vacuum of space, the sound of a lone scream isn't something that can be heard. Not just because the human body would erupt if exposed to space, but for sound waves to travel they need a medium – solid, liquid or gas – to move through. For example, when the skin of a drum is struck, vibrations cause a chain reaction of moving air molecules, pushing them together and creating a sound wave. In space no such medium exists. That's not to say that sound can't travel through space at all – it can, but very inefficiently – so if you find yourself screaming in space, no one will hear you.

Sound needs a medium to travel through

## 5 Famous prisoners of the Tower of London

### 1 Anne Boleyn

King Henry VIII's second wife was imprisoned at the tower, falsely accused and convicted of adultery, incest and treason. On 19 May 1536 she was executed, beheaded by the blade of sword.

### 2 Guy Fawkes

As a chief conspirator in a plot to blow up parliament, Fawkes met his end on 31 January 1606 after being imprisoned in the tower. As he was walking onto a hanging platform, Fawkes jumped from the ladder, breaking his neck and then dying.

### 3 Queen Elizabeth I

Queen Mary I believed Princess Elizabeth was plotting against her, ordering her incarceration in 1554. A lack of evidence for Mary's theory resulted in her release after only a couple of months.

### 4 Lady Jane Grey

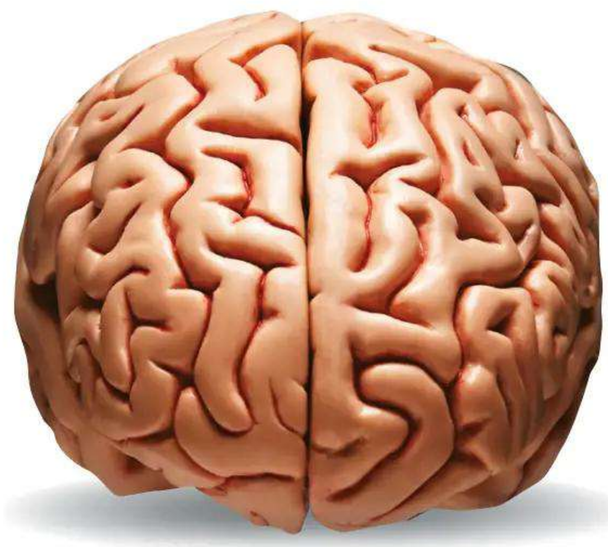
She was queen for just nine days after her father-in-law John Dudley persuaded a dying King Edward VI that Jane should be chosen as his successor. Deposed by the legitimate heir Mary, her and her husband were imprisoned in the tower and executed in 1554.

### 5 The Kray Twins

As the last prisoners in the tower, these London gangsters were notorious murderers and thieves. However, these were not the crimes that landed them in the tower, but for assaulting a corporal after failing to report for national service with the Royal Fusiliers.

© Getty / Illustration by Adrian Mann

# Psychology



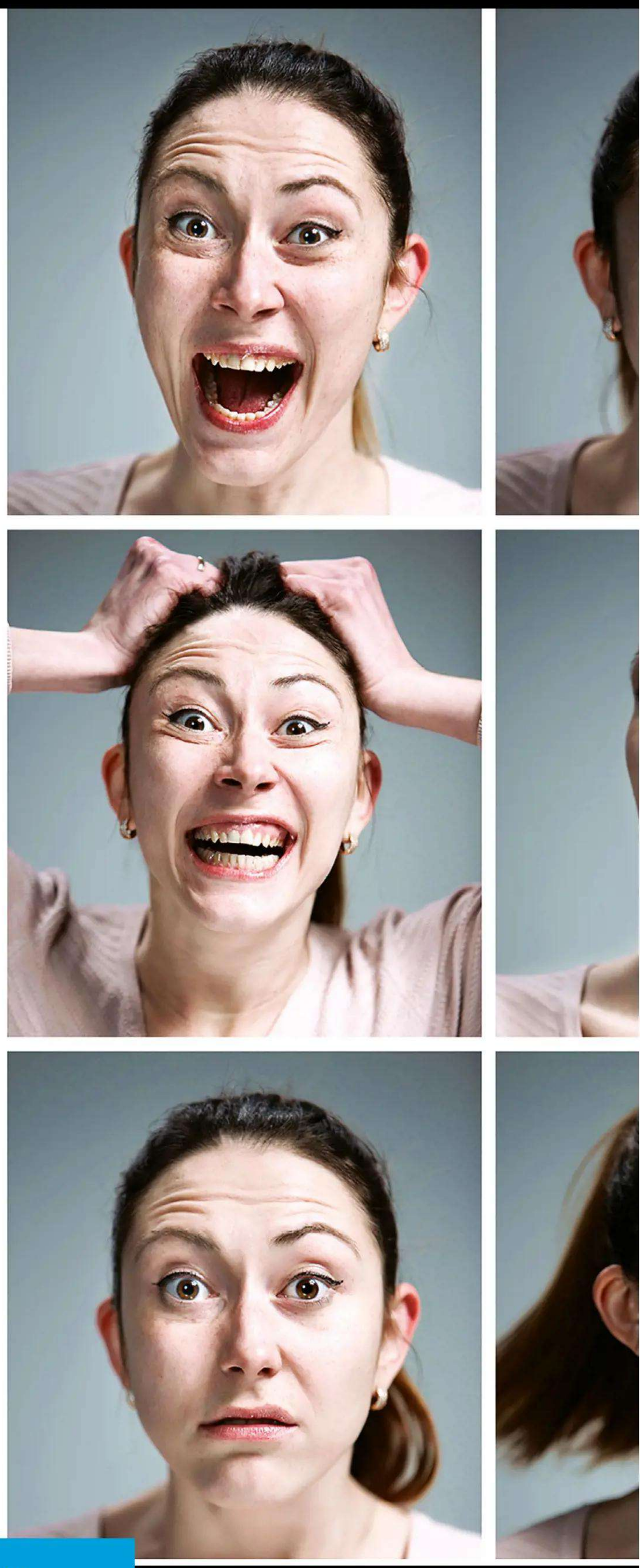
# The science of emotions

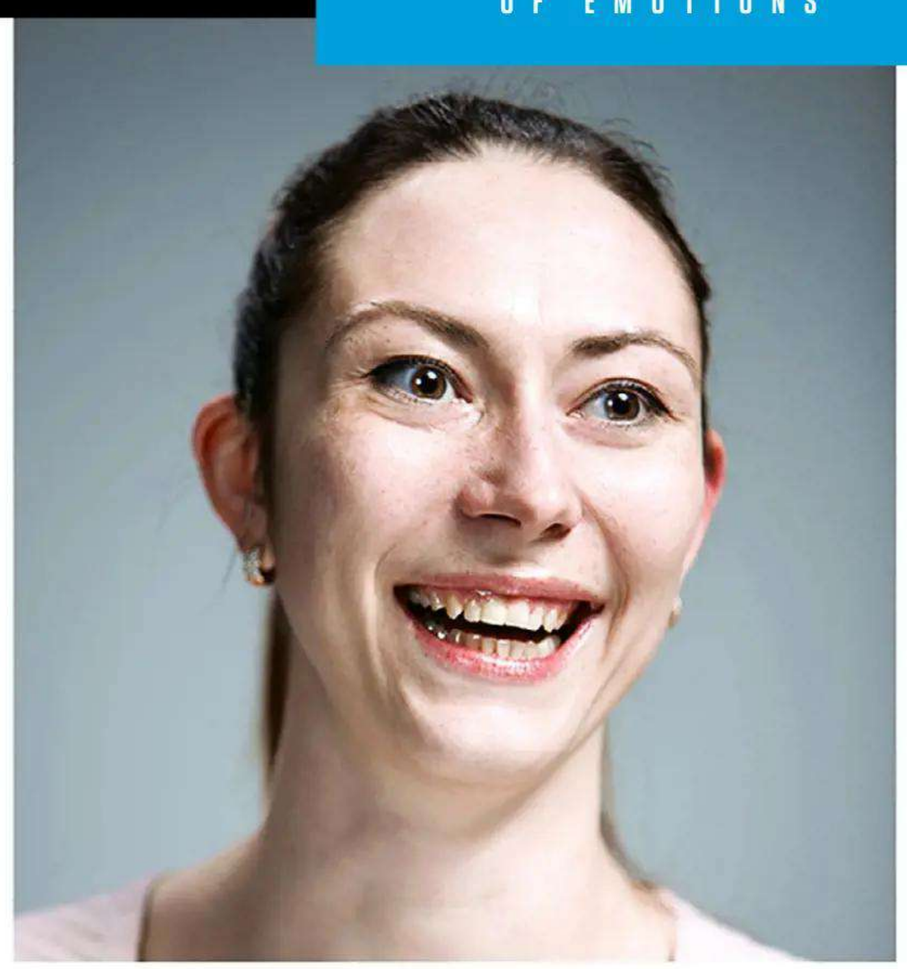
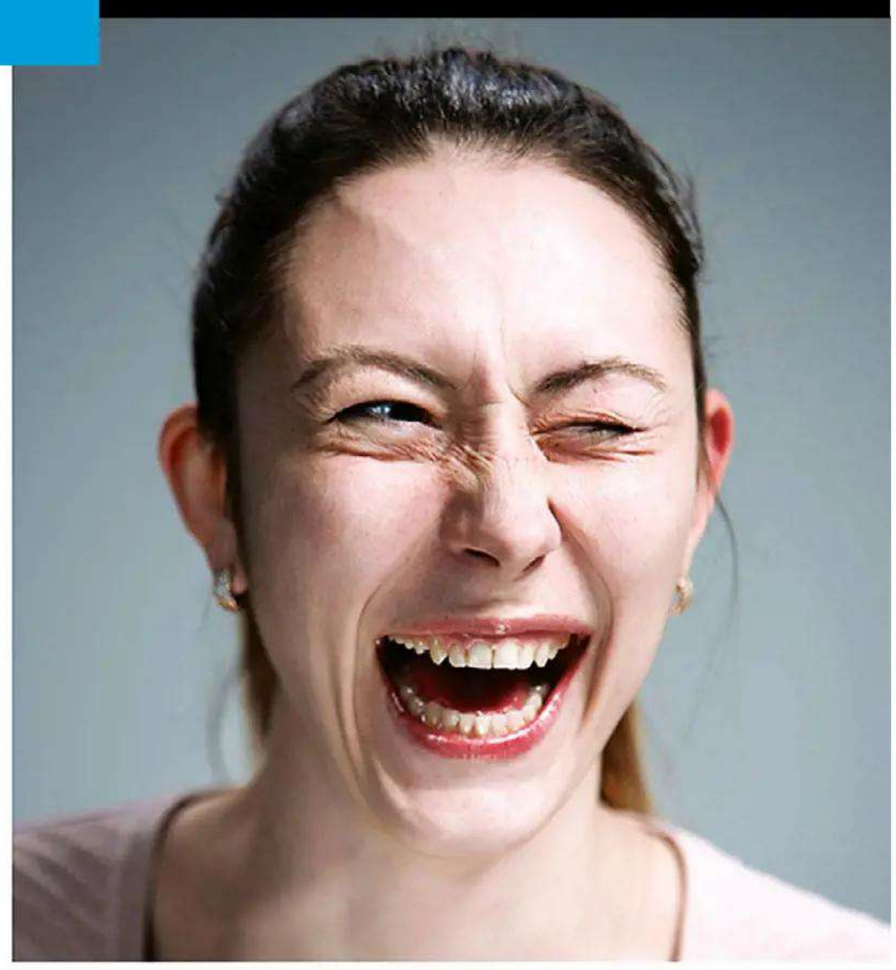
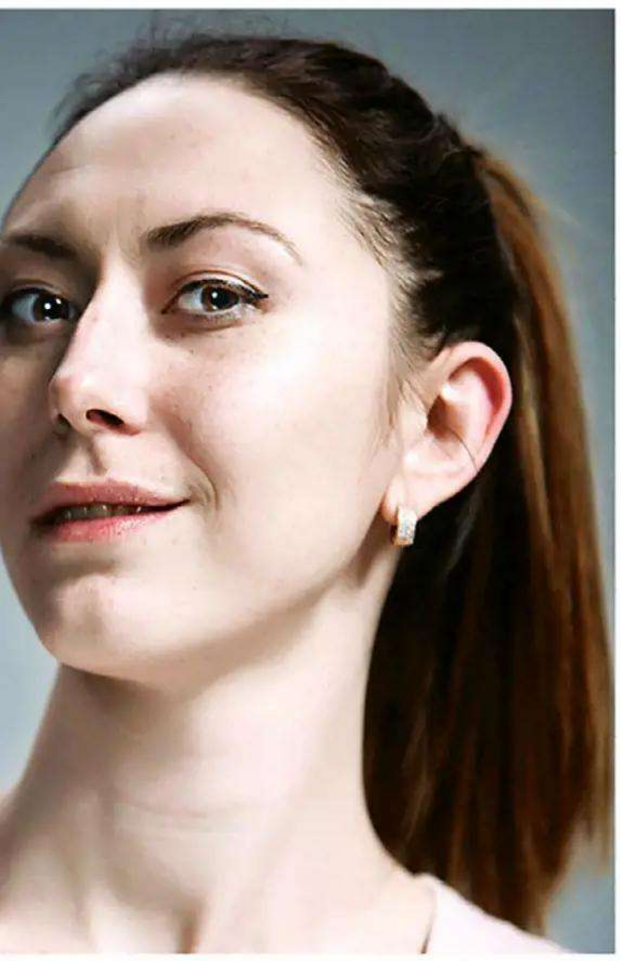
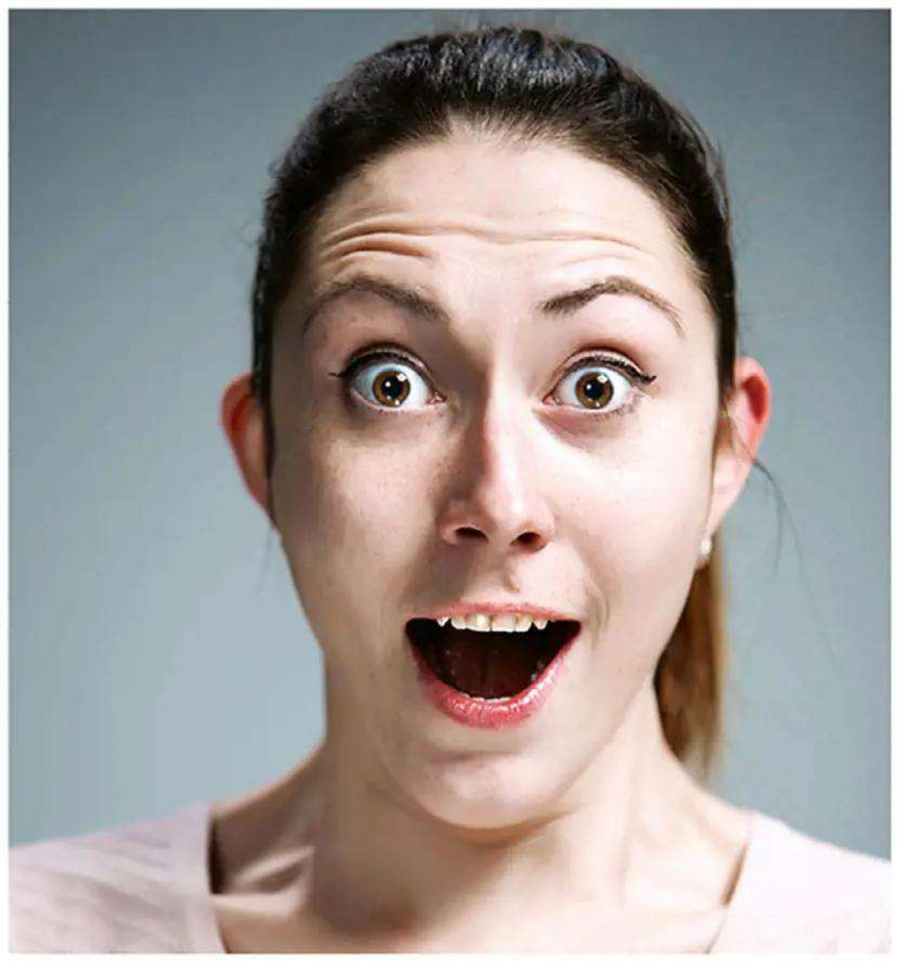
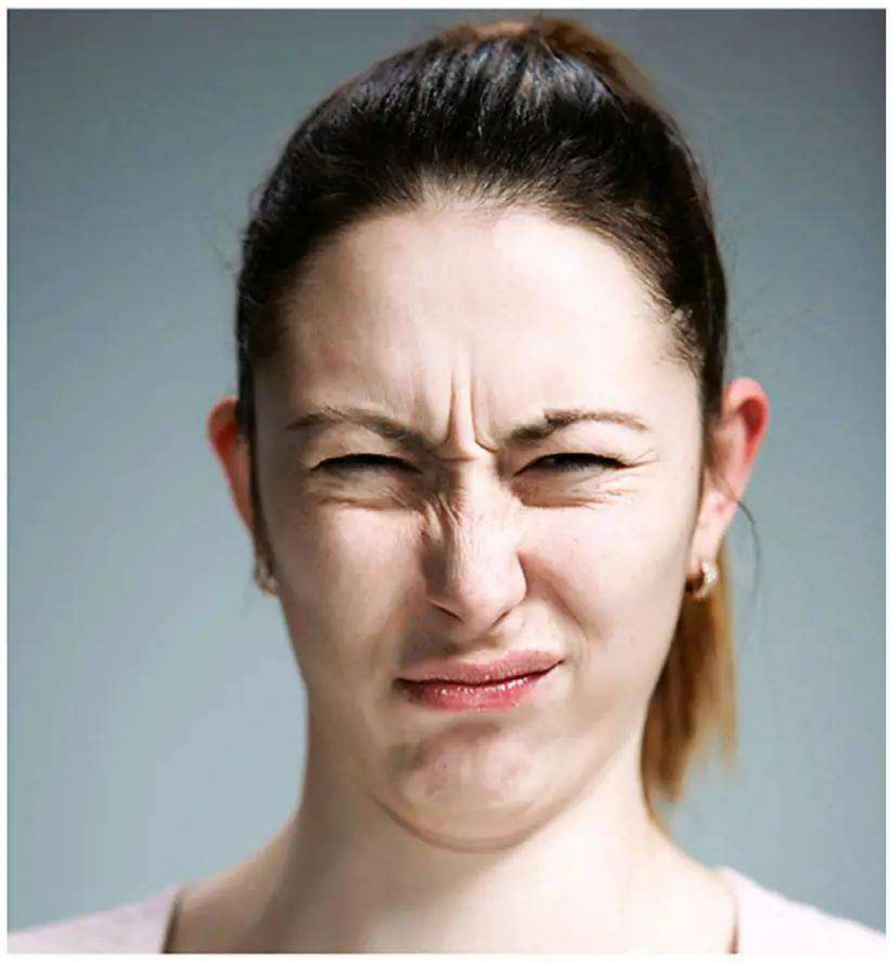
*How our ancient brains evolved the perfect way to keep us safe by controlling the chemicals in our minds to moderate our behaviour*

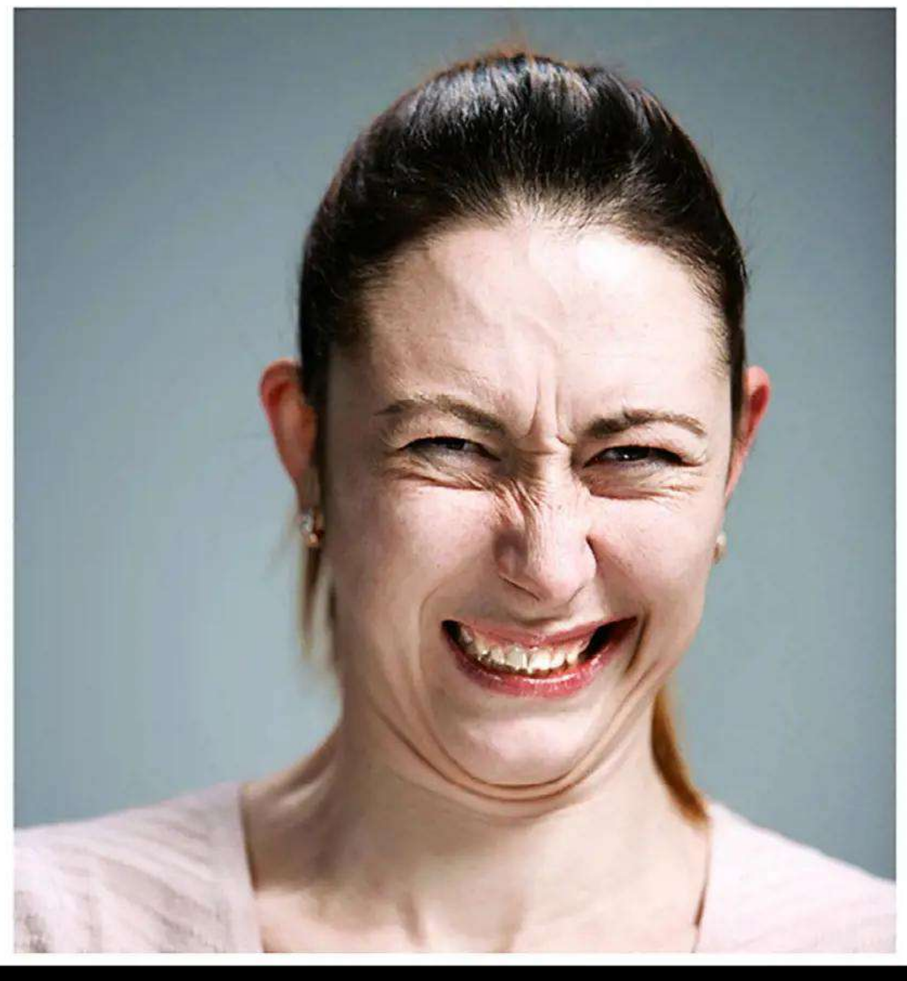
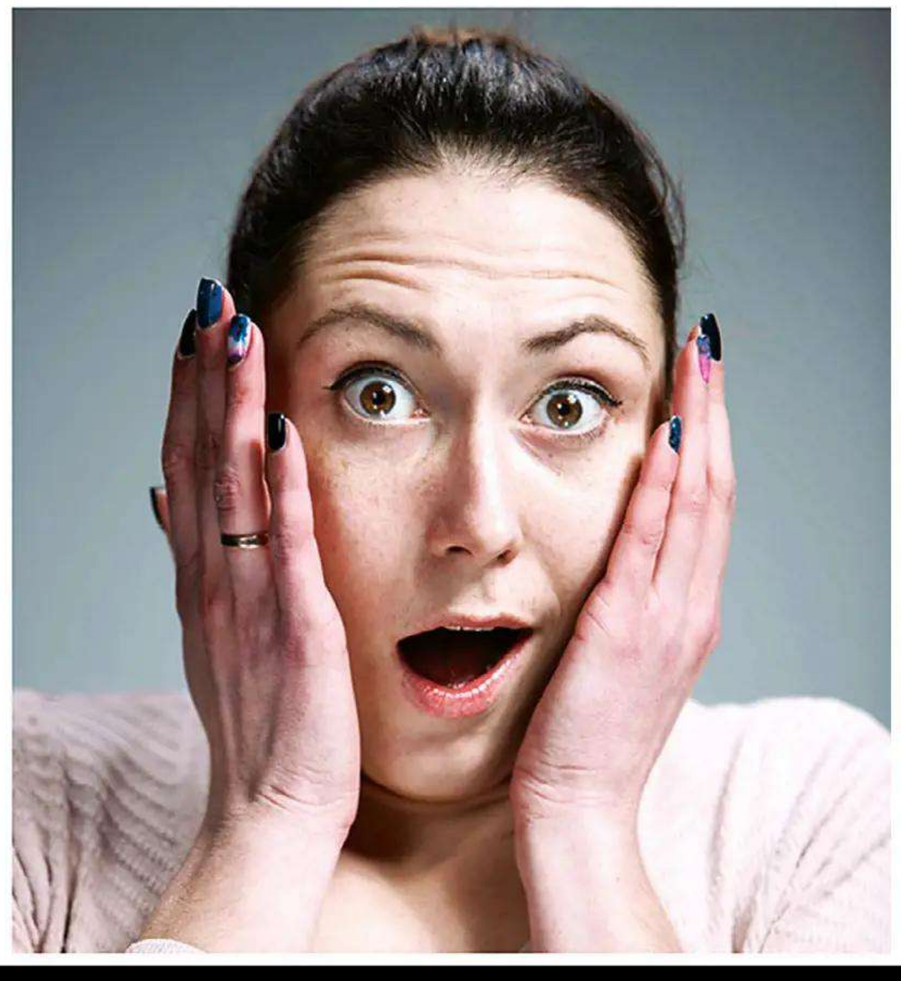
How are you feeling right now? Are you relaxed laying on your sofa and listening to the gentle sounds of the dawn chorus outside your window? Or maybe you are tense with your shoulders hunched up around yourself as you try to get five minutes peace in a busy office? You would think that it is easy to work out if we are happy or sad, angry or calm, but humans cycle through such a vast array of emotions throughout their lives it can be difficult to distinguish them from one another.

Emotions are not a simple experience. Every time you feel something your body initiates a physiological change, a chemical release and a behavioural response. This process involves multiple processes working together, including your major organs, neurotransmitters and limbic system. Your limbic system is the most primordial part of your brain, thought to have first evolved in early mammals. It's filled with ancient neural pathways that activate our emotions in response to stimuli and controls our fight-or-flight response through the autonomic nervous system.

This response evolved from a need to make decisions based on our emotions. As our body fills with adrenaline and our heart starts racing we prepare to react. Do we stay to fight the bear that has come scavenging for food, or do we flee to somewhere safe? We can still feel the effects of



© Getty

this response. When we are confronted for not doing the dishes we might feel the same fight-or-flight response as our adrenaline starts to flood our system. Our heart rate and breathing increases, the fine hairs on our arms might stand on end, and our hands feel clammy as we decide if we are going to stay and argue or if we are going to escape to to safety of our bedroom.

The biological sensations in our bodies in response to emotions can feel very similar to one another. Imagine your palms sweating, feeling your cheeks warm as they flush red, and your heart pounding in your chest. You could feel this because you are sitting nervously in the dentist's waiting room, or you could be excited as you wait to see your loved ones after they return from a holiday – the physiological reaction is the same. The interpretation of emotions is our logical brain rationalising these responses and describing them as feelings. We take into consideration the context and label our emotions accordingly. However, we don't all do this the same way. Because our bodies cause different floods of chemicals in response to different environmental triggers, each person naturally reacts to situations differently.

Have you ever seen someone who is being berated in a meeting but facing the onslaught with nothing more than a slightly raised eyebrow? Or watched as someone finds out some bad news but keeps their composure? You are sure that you would have raised your voice or burst into tears, but our responses are defined by how our neurons are networked together. Our past experiences and genetic predispositions influence our brain chemistry and therefore our physiological responses, which in turn determine how we react to various situations – like someone cancelling on us last minute, or having a friend surprise us by showing up at the front door unannounced.

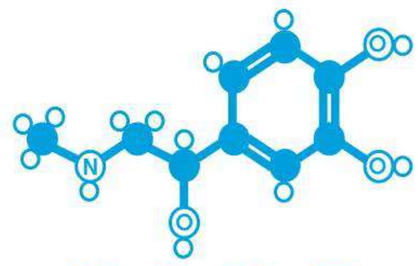
At times our emotions can seem like an irrational response, but our brains have carefully evolved these mechanisms with just one target – keeping us alive. While we interpret different emotions as positive or negative, the most ancient parts of the human brain developed them on the principle that we must survive. We evolved emotions as a means of communicative function and to help us navigate social interactions and our environment safely: they are designed to protect us. Our fear responses were originally a

**"We feel our emotions, and not just in our head and heart – our bodily state changes to react to the chemical storm in our system"**

# The chemistry of emotions

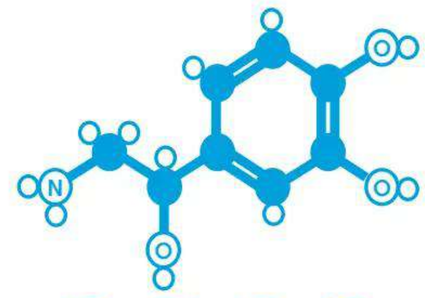
**Where two neurons meet, a very small gap (synapse) exists between them. The electrical impulse travelling along the axon of the neuron must convert into a chemical signal to bridge this gap. The chemicals that do this are called neurotransmitters. These so-called chemical messengers are involved in our different responses to situations.**

**Your emotions depend on fluctuating levels of neurotransmitters, which cause the activation of different parts of the brain responsible for different moods, or activate parts of the brain that trigger the stimulation of the autonomic nervous system.**



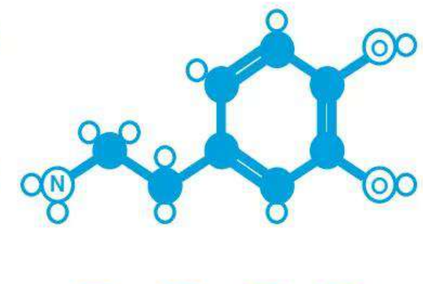
**Adrenaline**

**Released by the adrenal glands that sit on top of each kidney, adrenaline increases the flow of blood to our muscles, raises our heart rate and dilates our pupils. It is crucial in our fight-or-flight survival response.**



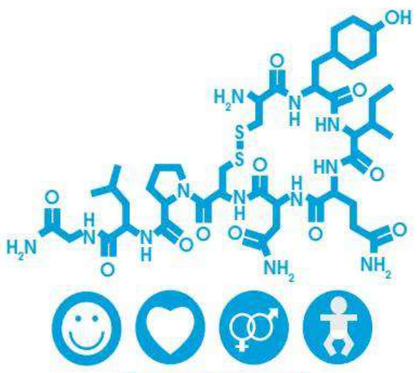
**Noradrenaline**

**Similar to adrenaline, the release of this chemical can result in increased levels of alertness, helping to prime us for action if needed. It also increases our blood pressure and widens our air passages.**



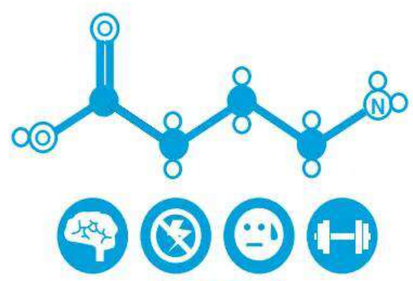
**Dopamine**

**This is the addictive reward chemical that your brain craves. It serves to motivate you to seek out the things you need for your survival. We can sometimes find ourselves enslaved by this ancient reward mechanism.**



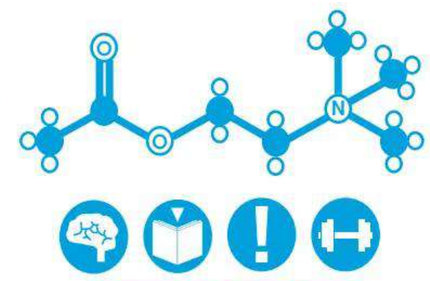
**Oxytocin**

**Also known as the 'cuddle hormone', oxytocin is released when you're close to another person. It's essential for making strong social bonds, and it's also a key part of why we want to trust people.**



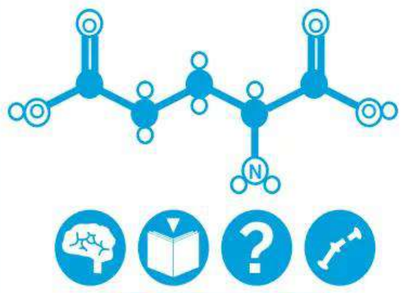
**GABA**

**Responsible for regulating muscle tone, gamma-Aminobutyric acid (GABA) also regulates the communication between brain cells. It can calm us down by reducing the rate at which our neurons fire.**



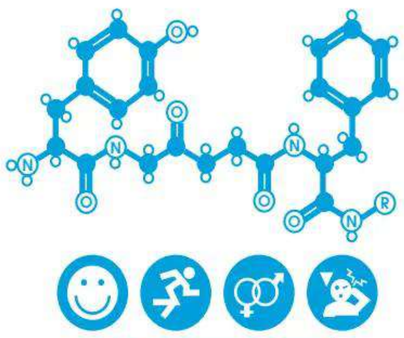
**Acetylcholine**

**This is the main neurotransmitter in the parasympathetic nervous system that slows our heart rate, contracts smooth muscles, dilates blood vessels and increases bodily secretions.**



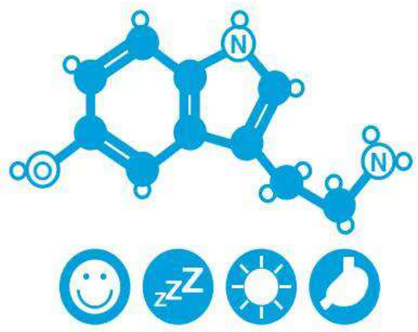
**Glutamate**

**The most abundant neurotransmitter in the vertebrate nervous system, glutamate is used by nerve cells to transmit signals to other cells. Too much of it can cause cognitive impairments.**



**Endorphins**

**Triggered by the sensation of pain, endorphins work to inhibit the transmission of pain signals. Capable of producing a sense of euphoria, studies have suggested endorphins may also be stimulated by laughter.**



**Serotonin**

**Serotonin is linked to our wellbeing and happiness, and our levels of it are affected by exercise and exposure to sunlight. It also helps to regulate our mood balance, sleep cycle and digestion.**

# The anatomy of emotions

Different areas of your brain and body are stimulated by different emotions

### Anterior cingulate cortex

This area is involved in assigning emotions to internal and external stimuli and is responsible for the vocalisations associated with our emotional states.

### Posterior cingulate cortex

This region is responsible for the recall of emotional memories, and it is stimulated when we daydream or recall past experiences.

### Parahippocampal gyrus

This area is responsible for storing emotional memories, and visual and auditory processing. It helps us interpret what we are feeling based on the context.

### Hypothalamus

This region regulates hormones and controls the autonomic nervous system in response to stimuli. It can trigger the release of insulin, increase heart rate or redirect blood flow, for example.

### Hippocampus

The hippocampus is responsible for making memories. It can help us regulate our emotions by allowing us to compare events to similar past experiences.

### Centre of emotion

Your brain recognises external stimuli and generates a physical and emotional response. It can do this even when we are not consciously aware of the stimulus itself.

### Amygdala

This small structure is responsible for detecting fear and preparing our bodies for an emergency. Stimulation of this area causes anxiety and defensive behaviour.

### Chemical messengers

When a nerve impulse reaches a synapse, it cannot jump directly to the next neuron. Instead, it triggers the vesicles (larger pink spheres) to release neurotransmitters (small pink spheres).

### Physical responses

Our emotions can lead to changes in our bodies, such as the feeling of 'butterflies' in your stomach, your heart racing, and so on.

### Septal nuclei (not visible)

These structures (located near the hypothalamus) are linked with feelings of social connection. They are particularly active when we have positive feelings towards others, such as unconditional trust or empathy.

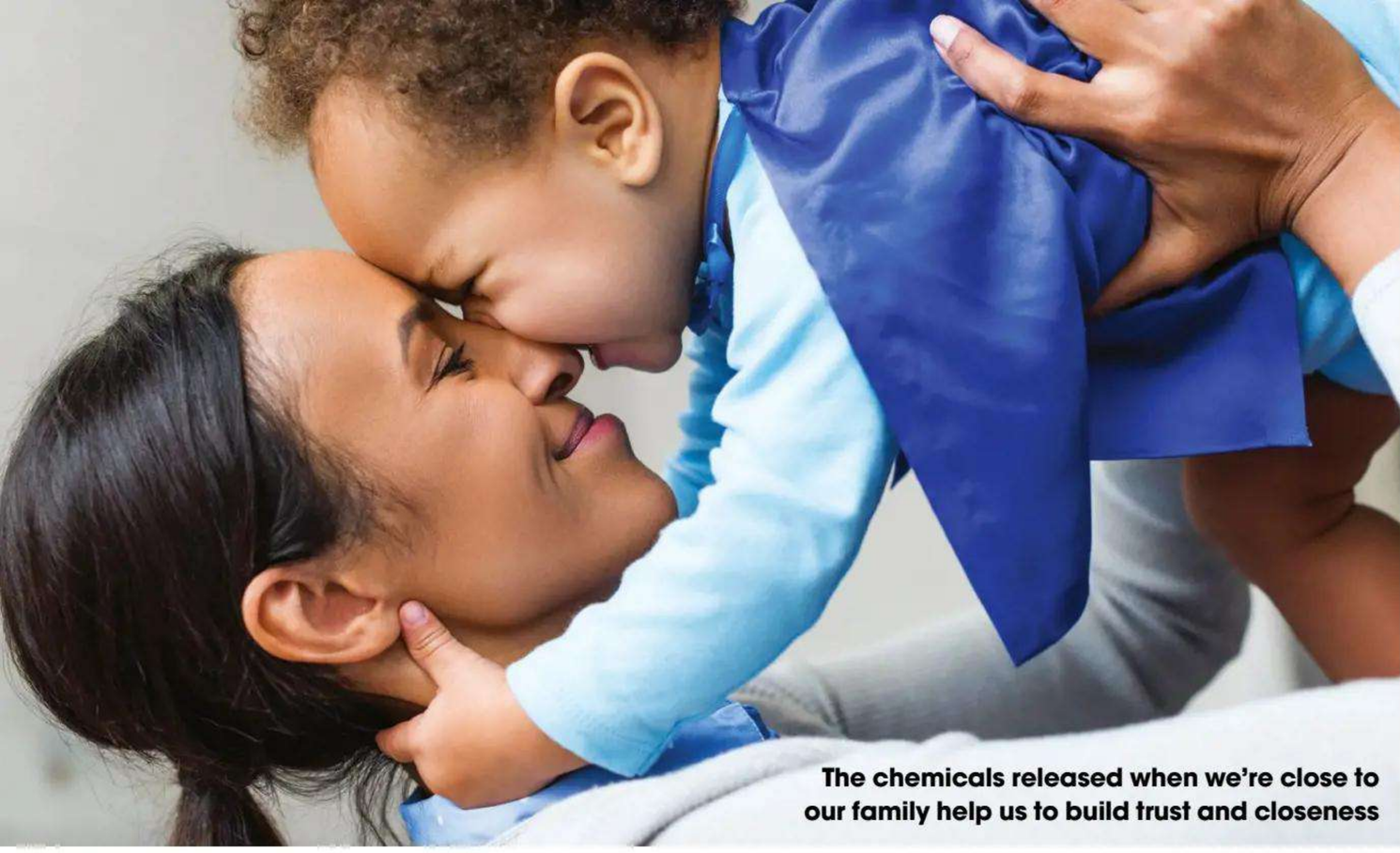
### Mind the gap

The neurotransmitters diffuse across a gap known as the synaptic cleft to reach the next neuron via receptors (beige).

### Transmission

When the neurotransmitters bind to the receptors, they cause the neuron's ion channels to open, letting ions (small yellow spheres) flow in, triggering the next nerve impulse.

© Getty



The chemicals released when we're close to our family help us to build trust and closeness

survival tactic that warned us of potential dangers, such as our innate unease around spiders and snakes. Then there is the feeling of disgust, which warns us of foods or other substances that may be dangerous.

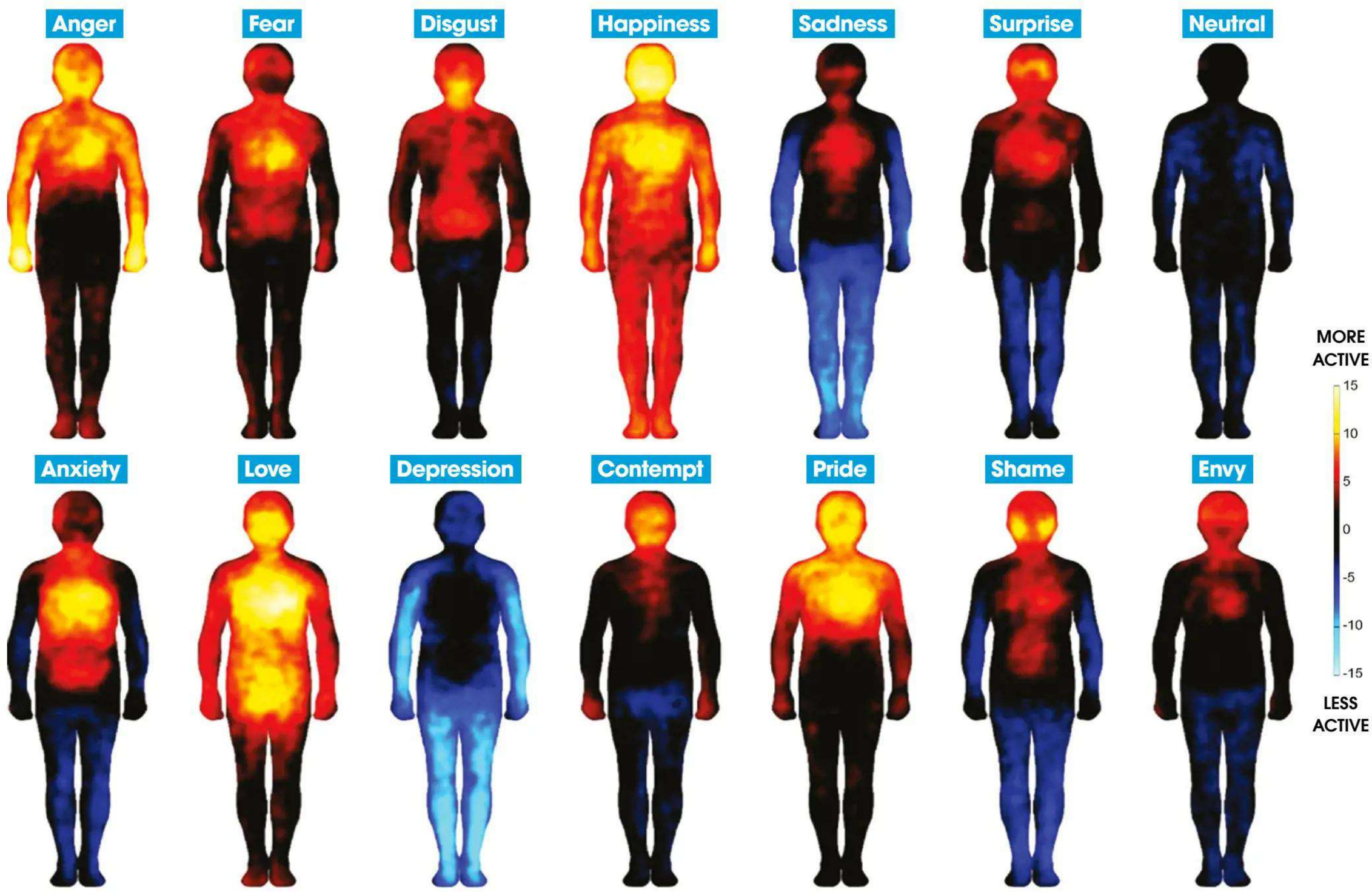
Our other emotions are responses to social interactions that keep us part of a group. We are fundamentally a social species, and throughout our evolution have relied on our tribe to help us survive by working together to find food and shelter. Anger is a response to perceived social threats or a signal of dominance, pride can help us to boost our social status, while shame is intended to decrease our

## Emotions as sensations

We feel our emotions, and not just in our head and heart – our bodily state changes to react to the chemical storm in our system. We might feel a tight knot in our stomach as we dread walking onto a stage to give a speech, or we might feel our cheeks flush red when we answer a question wrong.

Researchers from Aalto University in Finland explored how humans physically feel their emotions by mapping the sensations topographically. Their findings were consistent across Western European and East Asian cultures, which suggests the way people feel during an emotional experience stems from a biological source rather than a cultural interpretation. The study also highlighted that emotions adjust our bodily state to either prepare ourselves physically to fight or flee or to encourage us to seek out enjoyable social reactions.

The study included over 700 participants from Finland, Sweden and Taiwan, and researchers induced different emotional states before asking them to colour bodily areas on images of the human body to describe in which areas they felt activity increasing or decreasing.



The emotional mechanisms in our bodies evolved to keep us safe and connect us with others

standing within a group. These emotions maintain the social balance of our tribe – who we follow, who we trust, who we care about.

The fundamental emotions that motivate us individually are almost always sadness and happiness. Sadness results from loss and serves the biological purpose of motivating a person to recover that loss, whether it is a young child searching for their mother in a supermarket, or trying hard to get a new job after being dismissed. But the ultimate human emotion is happiness, and we are all in search of it.

When you're sitting around a campfire, safe in the countryside with some close friends and good food, you feel happiness because you have found the resources that your primitive brain is seeking. Our species is drawn so much to happiness because this emotion is our brain's reward system for finding environments where we are free from threat. A healthy human brain copes with sadness when social bonds are broken, communicates with our loved ones and can recognise and regulate our emotions even when they do not feel particularly positive.

The next time you sit in an airport departure lounge, look for the emotions. Our bodies have created these experiences – the tears as we say goodbye, the smiles and laughter as we are reunited – for the purpose of keeping us alive. Our emotions and feelings are fundamentally what make us human, but it means we're in for a bit of a rollercoaster along the way.

**"Reading the emotions of others is a vital skill for navigating our way through life"**

We may have more emotions than we are able to express in our languages

## How many emotions do we have?

It has long been thought that there are only six different emotions: anger, disgust, fear, happiness, sadness and surprise. It has been hypothesised that any other emotions are just a combination of these basic feelings, such as anticipation being caused by a mixture of fear and happiness. However, a recent study published in Proceedings of the National Academy of Sciences of the United States of America from researchers at UC Berkeley suggests that we may have many more emotions that are distinctively different to one another, but still related.

The study used 2,185 short videos with the intent to evoke emotions in the 853 participants. Clips included a cute baby playing with some fluffy puppies, a man holding a tarantula inside his mouth, and a happy couple getting married. Participants were asked to record how the videos made them feel and how strongly it evoked a response. The study suggests that there are 27 distinct emotions, including awe, awkwardness, calmness, confusion, disgust, nostalgia, sadness, sympathy, horror and triumph.

## Universal expressions

Reading the emotions of others is a vital skill for navigating our way through life – it would be awkward to misunderstand your friend as happy when they're actually angry with you.

There has been a long-established view that the way we express our feelings using our facial expressions is universal and crosses all cultures for seven basic emotions: anger, disgust, fear, joy, sadness, surprise and contempt. For over a century, studies have explored the theory of universal expression by asking people to interpret photographs displaying various emotions, although there are some cultures around the world that do not have the same perception of certain emotions.

One study found that people living in the Trobriand Islands off Papua New Guinea didn't interpret images of people who were wide-eyed with their lips parted as they gasped as a sign of fear. Instead, the Trobrianders interpreted this emotion as anger. This research is some of the first to suggest that how we express our emotions is not universal, and may differ between societies.

While the expression of happiness and sadness is generally the same all over the world, surprise and fear can be interpreted differently between cultures

© Getty; L Nummenmaa et al, Aalto University

# Why do we Lie?

*It's not just bad behaviour – deception is a product of evolution and it gives your brain a real workout*

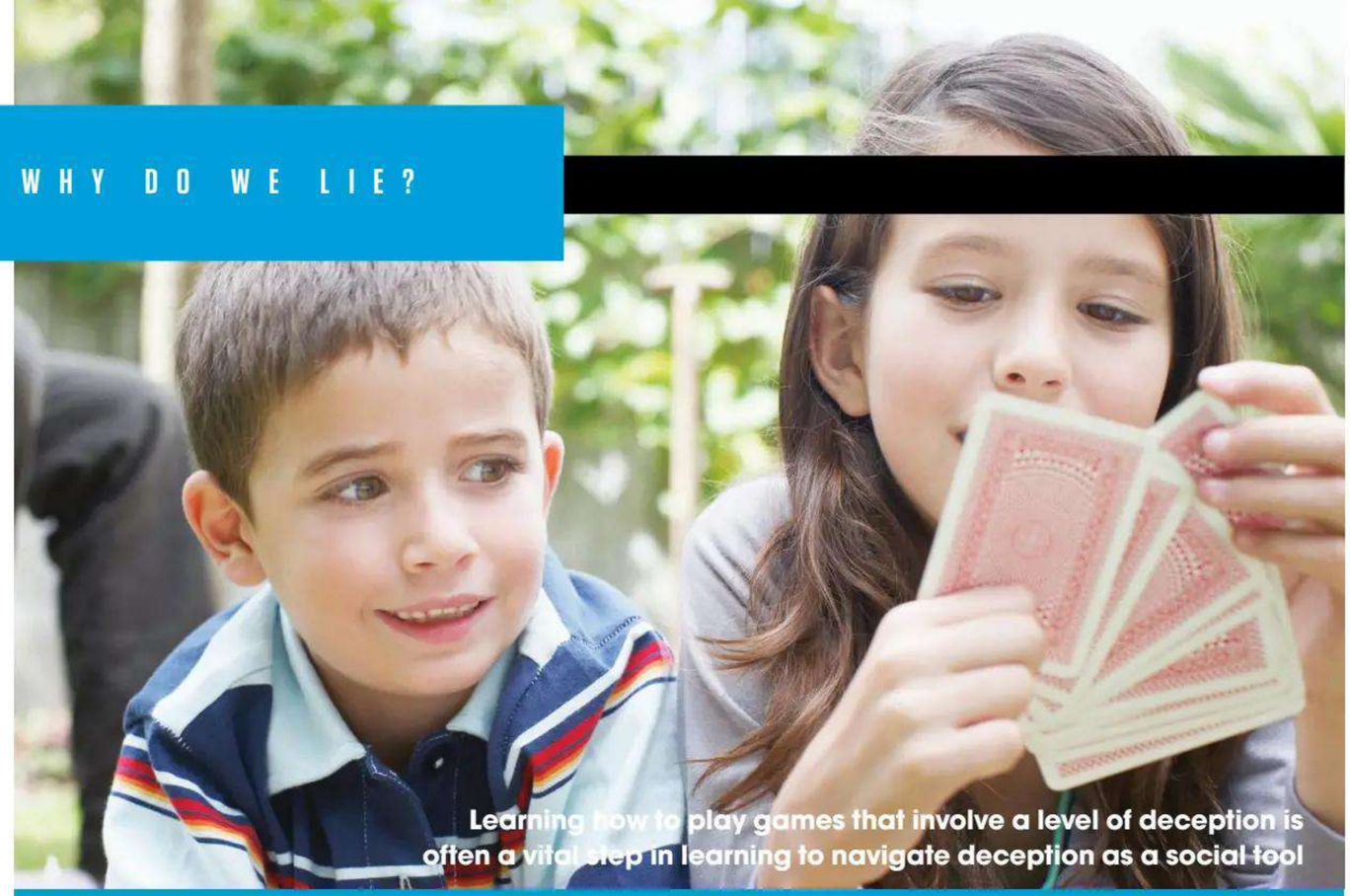
Your dog really did eat your homework, and you have no idea who took the last biscuit from the sweet jar. Lying is in your nature, but don't worry – it's in the nature of most humans. It's a technique that has evolved over billions of years, so it turns out you might not actually have that much to feel bad about.

Humans are social creatures, and we have our giant brains to thank for this. They evolved to be so large because we needed the extra space to be successful at communicating with others and keeping our social group happy. This has a lot of advantages. If you can build bonds with other humans you can access more resources because your friends and family will share food and shelter, helping you out when you need it. But to keep these close connections sometimes we need to lie. Throughout hominid history it has been a genetic advantage to be a good liar, as it supports social bonds, and therefore you are more likely to survive and pass on your genes. Bending the truth, playing fast and loose with the facts, telling a tall tale - whatever you call it, lying is something that most individuals in our species find really easy.

Although deception is frowned upon by society, it actually evolved as a way to fine-tune our social skills and strengthen our relationships. Have you ever told a friend that you really loved the dinner they had cooked for you? Or maybe you have lied to your mum about accidentally breaking something in the kitchen? That's these evolutionary mechanisms kicking in, and whether it was to protect your reputation or just avoid upsetting someone, it probably worked well to protect your relationships (if you didn't get caught that is).

## YOUR BRAIN ON LIES

Lying is a creative task, and it's much harder for our brains than just telling the truth, as it requires remembering lots of different information to keep the story consistent. Even more complicated is our ability to lie to ourselves, an extreme level of deception that requires keeping two pieces of information in our heads and ignoring one.



Learning how to play games that involve a level of deception is often a vital step in learning to navigate deception as a social tool

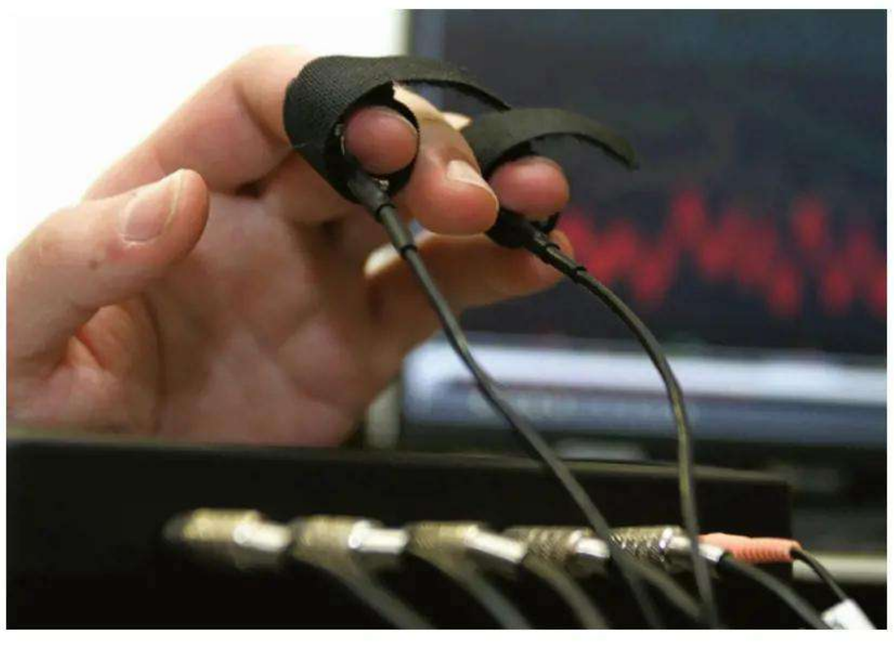
## "We're not the only species that has developed deceptive tactics"

Whatever reason you are lying, and however complex the lie, there are three main parts of the brain that you use when you are being deceptive: the anterior cingulate cortex, which is responsible for monitoring errors, the dorsolateral prefrontal cortex which controls behaviour, and the parietal cortex, which processes information from your senses. These parts become more active when lying, and they can be seen using functional MRI scanners – a much more advanced version of a lie detector.

However, we've not always had the technology to help us detect a liar. For most of history we have relied on our observation and social skills. We learnt how to monitor other people's behaviours for signs they were not telling us the truth; unusual eye contact, signs they might be sweating more, elaborating on a story with details that just don't sound believable. As our ability to lie evolved, so did our ability to detect a lie. This has come in helpful because not every lie is told because we want to keep our friends. Sometimes lying is used to manipulate others for personal gains, such as scamming people out of money. Being able to detect a lie is helpful for keeping our resources safe from people who are dishonest.

### LYING IS NOT UNIQUE TO HUMANS

We're not the only species that has developed deceptive tactics. The skill has been mastered throughout the animal world, notably by tufted capuchin monkeys, which will shout out false alarms to scare away older individuals from food, and the polka-dot wasp moth, which mimics the same clicks of the bad-tasting delicate cycnia moth to ward off predators. These animals developed these tactics to protect themselves rather than strengthen social bonds.



**Polygraphs, also known as lie detectors, monitor a person's breathing rate, pulse, blood pressure and perspiration to try to determine if someone is lying**

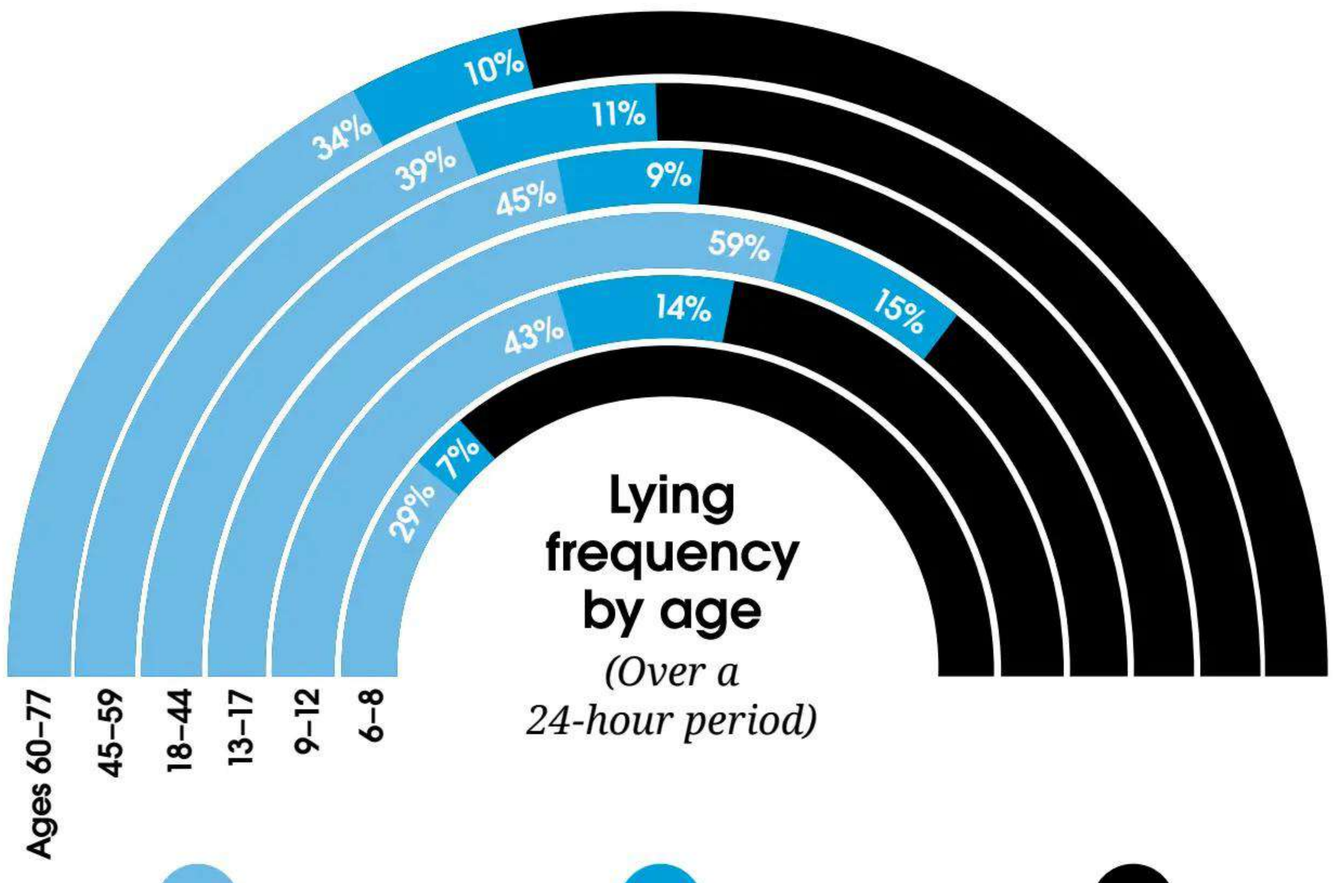
## When do we learn to lie?

It's thought that we learn how to lie much younger than we probably think, with some research suggesting it may have begun as early as six months old. Over the years we perfect the art, and some estimates suggest by the time we are in college we may be lying to our mothers once every five interactions.

The developmental model of lying was first proposed by researchers Victoria Talwar and Kang Lee. Their work shows that children between the ages of two and three start telling primary lies – basic deceptions to cover up mistakes or bad behaviour – but without considering whether the listener will actually believe the lie. Around the age of four children start to tell secondary lies, more crafted and complex lies that are more believable. By age seven or eight children start telling tertiary lies, using consistent facts and follow-up statements. This is an ability that will stay with them for the rest of their lives.

## Lying is a matter of age – honestly!

**While our tendency to lie peaks in our teens, we don't all make for honest adults**




These lighter sections are the percentages of people telling one to five lies a day.

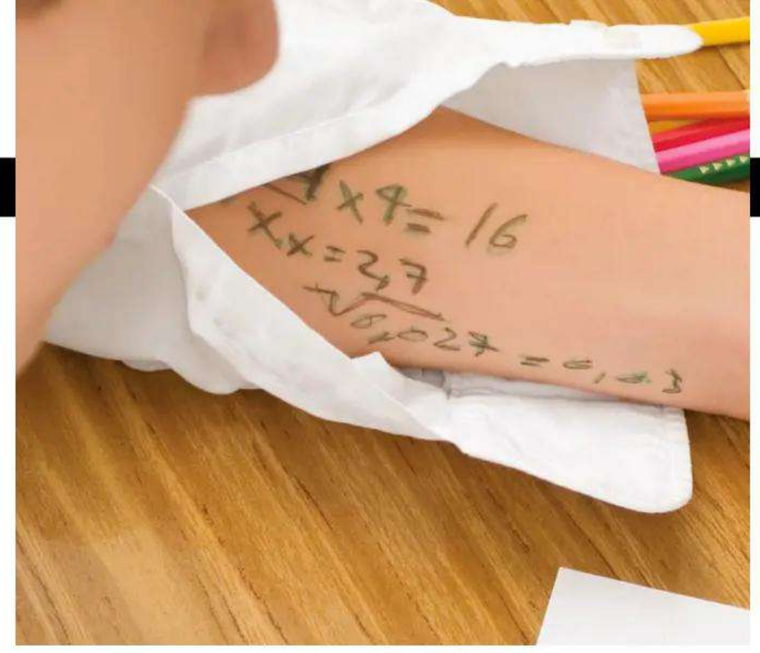
The percentages in the darker sections are those people who told more than five lies in a single day.

No lies told.

© Getty

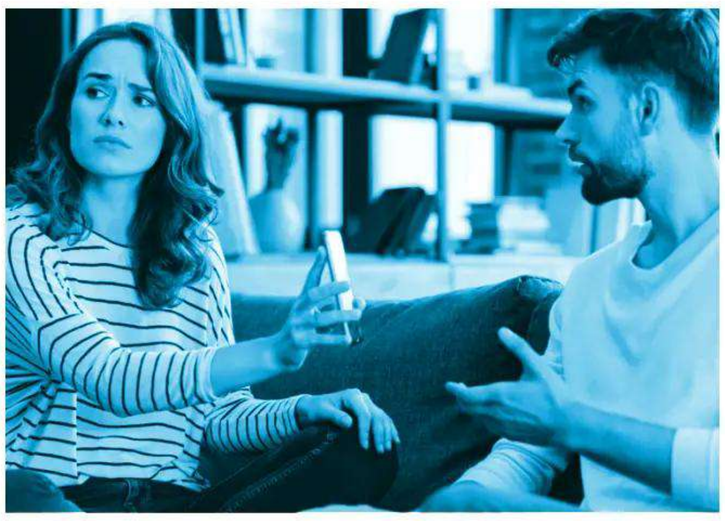
# How to catch a lie

*It's all in the body language*



Cheating in a test could be an example of personal advantage or self-impression lying

**1 Intense eye contact**
Eye contact usually suggests honesty, and it is tempting for someone telling a lie to break eye contact. So they will start making more eye contact than usual, overcompensating.



**2 Contrary confirmation**
Informal language and phrases that express they are being honest (such as 'believe me' or 'to be totally honest') hints that someone might not be telling the truth.

**3 Frozen upper body**
People tend to move less when they are being deceptive, gesturing with their hands less frequently and sometimes completely freezing their entire upper body.

**4 Prolonged eye closing**
Usually, people will blink for between 0.10 to 0.40 of a second, but when someone lies they often have their eyes closed for even longer than a second.

**5 Head shaking**
If someone says 'yes' but they shake their head 'no' at the same time, their body language might well be giving away the real answer - and vice-versa.

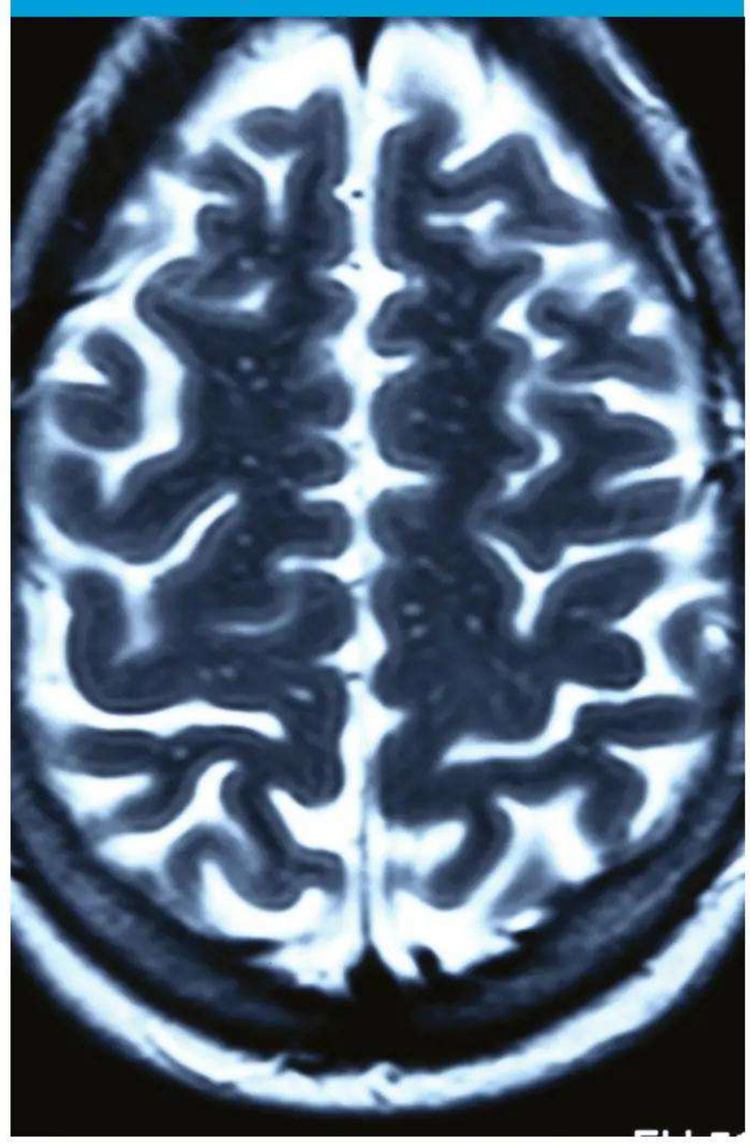
**"It is unknown if the increased white matter is the cause of pathological lying or if the practice of frequently lying can cause structural changes in the brain"**

## Pathological liars

Pathological lying is a term that refers to the act of lying so naturally and instinctively that the individual finds it easier than telling the truth. Sometimes they can even believe their own lies. It is a condition that can be damaging to the lives of the sufferer as it destroys careers and relationships.

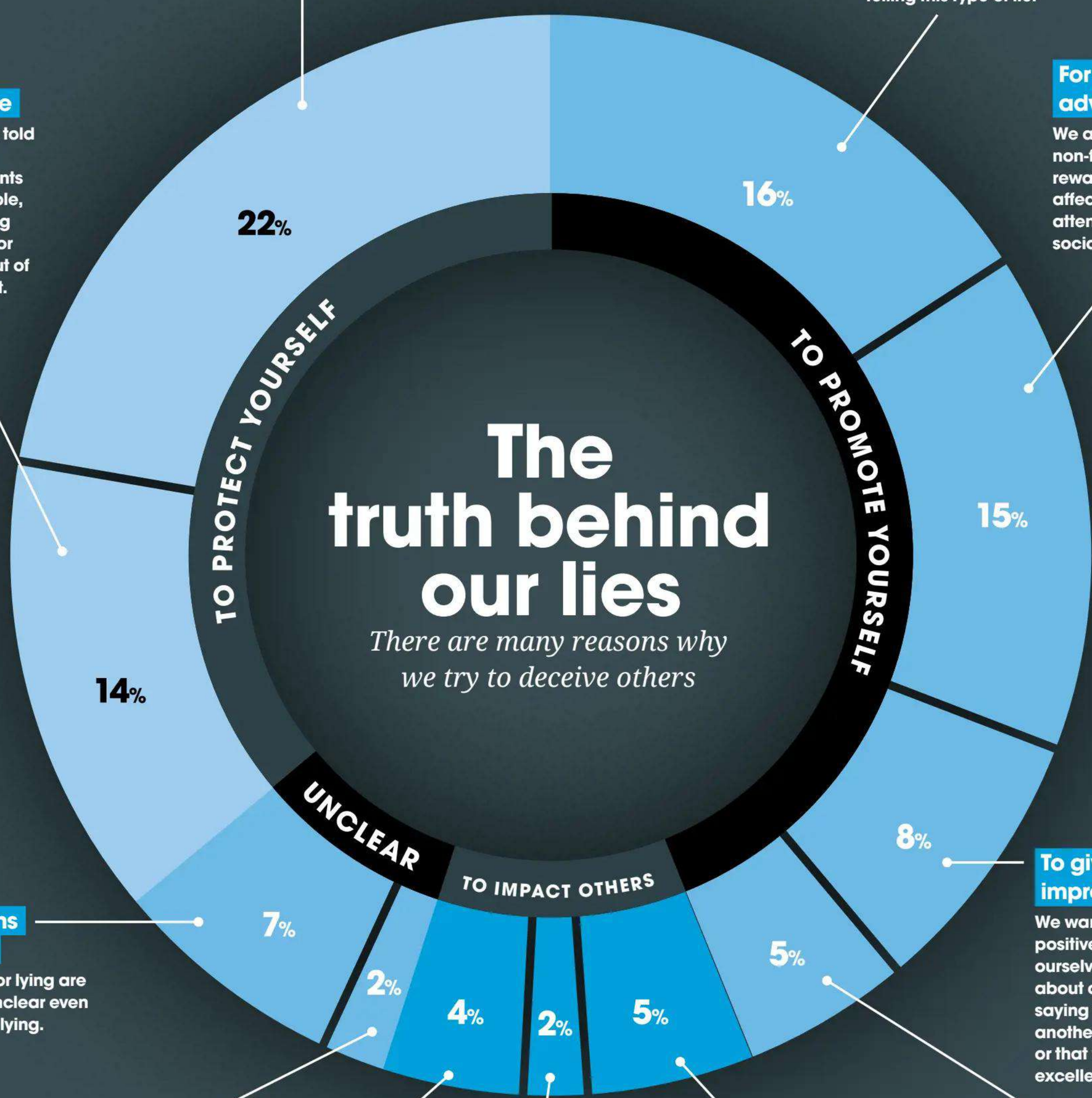
Neurologists have discovered that there are physiological differences in the brains of pathological liars, who have 22 to 26 per cent more prefrontal white matter and approximately 14 per cent less grey matter. It's thought that this difference means pathological liars are more able to make connections between different memories and ideas. However, it is unknown if the increased white matter is the cause of pathological lying or if the practice of frequently lying can cause structural changes in the brain.

It's grey matter that helps us to control our impulse to lie to others



# The truth behind our lies

*There are many reasons why we try to deceive others*




**To avoid punishment**
We have broken the law, made a mistake or committed a misdeed that we want to cover up.

**For economic advantage**
There is some financial reward, like a promotion or a pay rise that we will gain by telling this type of lie.

**Social avoidance**
Some lies are told because the individual wants to avoid people, such as saying they are sick or busy to get out of a social event.

**For personal advantage**
We are seeking a non-financial reward, such as affection, attention or higher social status.

**To give a good impression**
We want to shape a positive image of ourselves so lie about our character, saying we speak another language or that we're an excellent cook.

**For reasons unknown**
The motives for lying are sometimes unclear even to the person lying.

**No real reason**
Pathological lying is a condition where an individual compulsively lies to excess, often serving little or no purpose.

**Malicious lying**
Hurting other people by lying to them is known as malicious lying and serves to put other people down. This is sometimes done as revenge or to cover the liar's own insecurities.

**To fit in**
Some deception comes from a desire to uphold social roles or avoid being rude in an attempt to fit in with the social group.

**Altruistic reasons**
We might lie selflessly for the benefit of other people, such as offering reassurance or complimenting them to make them feel better.

**For humour's sake**
Some lies are told for the purpose of making other people in our social group laugh, such as exaggerating a story or making up a funny anecdote that did not happen.

© Getty

PSYCHOLOGY

# How does hypnosis work?

*Discover the science behind hypnosis, how it's used to alter behaviour and even assist in surgery*

It makes for some lighthearted entertainment when a group of willing volunteers walk on stage and stare blankly at a swinging pocket watch before remarkably transforming into a group of clucking chickens, but is hypnosis more than just a stage show?

Hypnosis is by no means a modern-day technique, with the first recorded medical use described in the Egyptian Ebers Papyrus, which was written in about 1550 BCE. Over time the skill of sending people into a deep trance evolved to tap into the subconscious and implant suggestions to change addictive behaviours or treat ailments.

However, much like many other aspects of how the brain works, scientists remain relatively baffled by the phenomenon of hypnosis. It is collectively understood that its success is based on a person entering a heightened state of relaxation and focus through verbal and visual guides, at which point it's believed that our brains are more susceptible to suggestion. There are two main theories as to why this works and what it does to our brains. Altered-state theory explains that hypnosis is much like sleep in the sense that when in a trance-like state the brain's processes work differently, although you are not awake to acknowledge them. The non-state theory suggests that a hypnotised person is still aware of what's happening, unlike when you're asleep, and they are actively participating in the hypnotist's instructions. However, there is still some debate and uncertainty behind which theory is correct.

So how do you become hypnotised? In a nutshell, a hypnotist or hypnotherapist 'induces' a person into a state of relaxation using verbal suggestion, typically using some sort of sleep analogy. After placing more and more emphasis on their imagination about something that is not in their real environment, a person begins to enter into a hypnotic state. However, not everyone is susceptible to hypnosis. A person's 'hypnotisability' can range from them being completely immune and unresponsive to any hypnotic technique to a small percentage of the population being highly hypnotisable and susceptible to suggestion. Those that are highly responsive to hypnosis have shown that the technique can be used during surgery. Some patients have even been known to respond to posthypnotic suggestions, whereby an instruction will be given for an action to be carried out years later.

As a method of therapy, those within the extreme limits of hypnotisability can benefit from the well-documented advances in treating problematic behaviours such as smoking, or the treatment of obesity and anxiety. Hypnosis is much more than a theatrical performance we can see on stage – it can be a rather useful medical tool.

## Stages of hypnosis

There's a host of different techniques used to induce a trance during hypnotherapy

### Priming

**The hypnotherapist may prepare or outline the patient's trance. This may involve an interview about the goals of the treatment.**

### Preparation

**The patient is placed in a comfortable position with their eyes closed. Breathing techniques may then be used to help relax the patient.**

### Induction

**This involves one of several techniques. The patient may be guided into a meditative state through visual cues, such as imagining a beach.**

### Hypnotic state/trance

**Following a successful induction the patient will then enter a pleasant state of heightened relaxation, both physically and mentally.**

### Suggestion

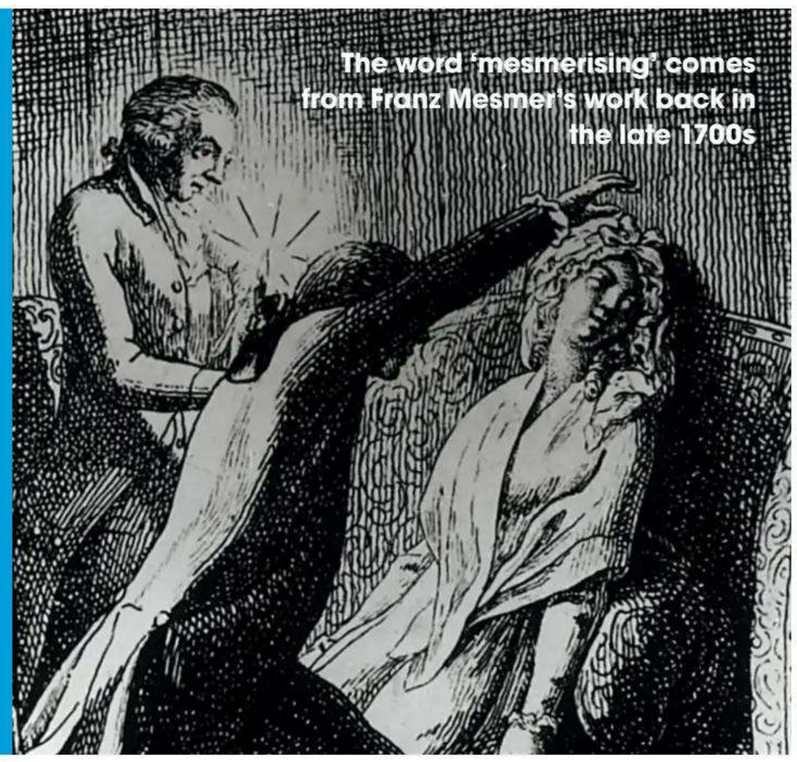
**Intended to replace or edit subconscious thoughts, a hypnotherapist will use verbal communication to make suggestions to alter behaviour.**

### Emergence

**A cue set by the hypnotherapist in the priming stage – a sound or word – may be used to bring the patient out of their trance-like state.**

## The invention of hypnotherapy

In the late-18th century, Mesmer believed that the body was surrounded by a magnetic 'fluid', and with the aid of a magnet or an individual thought to have a 'higher natural magnetic force', such as himself, he could alter the fluid and thus relieve the patients of their issues, all while putting them into a suggestive mental state. Word spread about Mesmer's technique – now known as 'mesmerism' – throughout Vienna, where he lived. However, so did rumours that the treatment was ineffective and had been disproved by his peers. As more and more people heard of the Mesmer scandal, he fled to Paris to continue his work of fraudulent mesmerism once again. Having built a new reputation, Mesmer secured high-profile clients, including royalty when Queen Marie Antoinette called upon his services. However, once again the scandal of his inaccurate science caught up with him, forcing him to travel around the rest of Europe before dying in Germany in 1815. Although Mesmer's theory of animal magnetism was fraught with inaccuracy, he did get one thing right: the suggestive mental state he induced in his patients went on to be the basis for the effective hypnosis we see today.



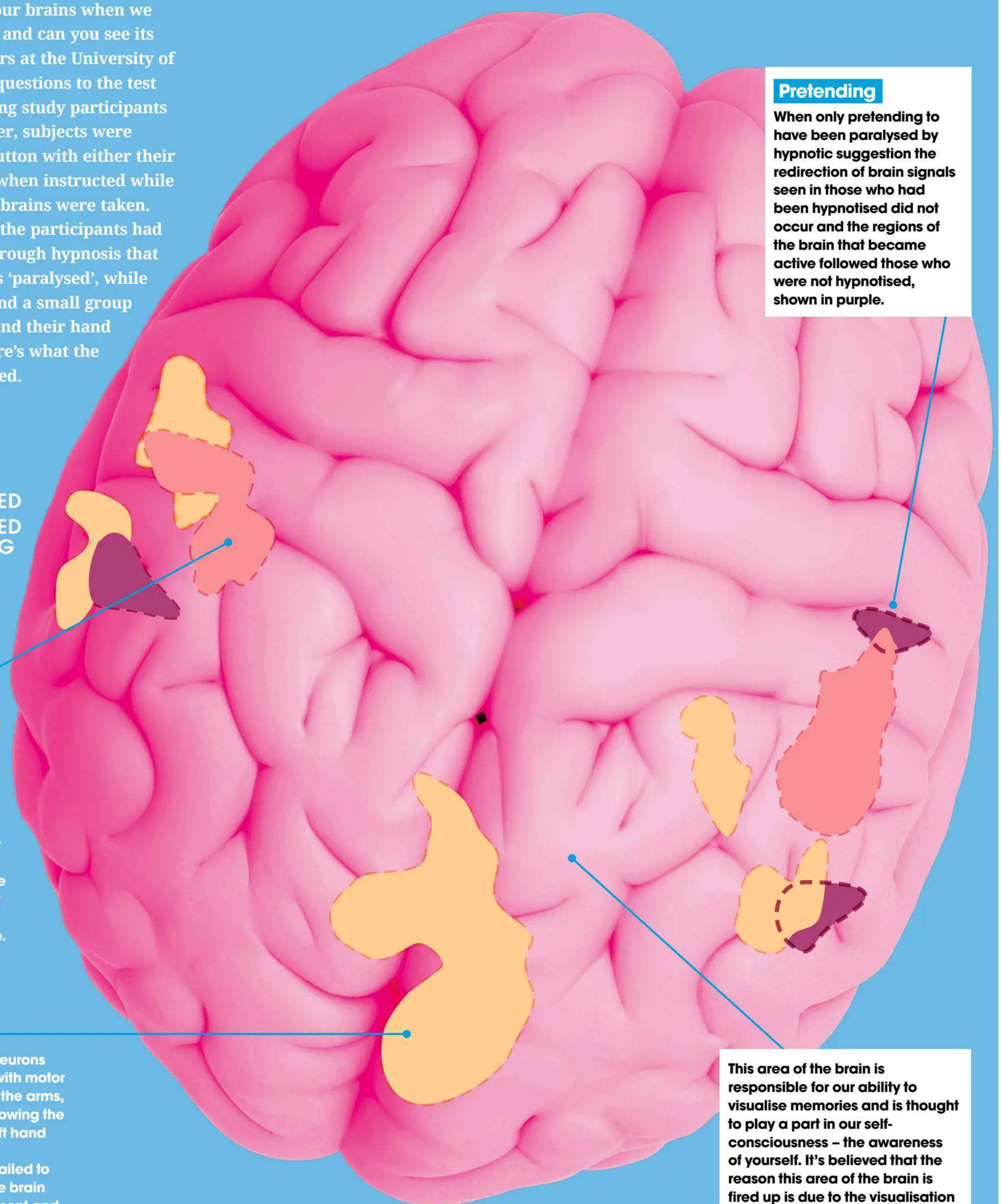
The word 'mesmerising' comes from Franz Mesmer's work back in the late 1700s

© Getty

# Hypnosis on the brain

**"Hypnosis is much more than a theatrical performance we can see on stage"**

What happens to our brains when we undergo hypnosis, and can you see its effects? Researchers at the University of Geneva put these questions to the test back in 2009. Placing study participants into an MRI scanner, subjects were asked to press a button with either their right or left hand when instructed while snapshots of their brains were taken. However, some of the participants had been instructed through hypnosis that their left hand was 'paralysed', while others were not, and a small group was asked to pretend their hand was paralysed. Here's what the brain scans revealed.




**Pretending**

When only pretending to have been paralysed by hypnotic suggestion the redirection of brain signals seen in those who had been hypnotised did not occur and the regions of the brain that became active followed those who were not hypnotised, shown in purple.

**Not hypnotised**

Shown in pink, the brain motor cortex responsible for the movement of the 'unparalysed' hand fired up to prepare for further movement. When instructed to use the left hand, the right region of the motor cortex became active.

**Hypnotised**

Shown in yellow, the neurons typically associated with motor skills, such as moving the arms, fired up. However, following the suggestion that the left hand was paralysed, these neurological signals failed to reach the region of the brain responsible for movement and were instead directed to the posterior region of the brain called the precuneus.

This area of the brain is responsible for our ability to visualise memories and is thought to play a part in our self-consciousness – the awareness of yourself. It's believed that the reason this area of the brain is fired up is due to the visualisation of the hypnotic suggestion that the left hand is too heavy to lift and therefore paralysed.

Much more than a viral trend, so-called 'chicken hypnosis' has been studied since the early 1900s

## Can animals be hypnotised?

You may have seen videos online in which a seemingly alert chicken is held on the ground and a line is drawn moving away from its beak. When directed to look at the line the chicken suddenly stops in its tracks. Appearing to be fixated and motionless, is the chicken truly hypnotised? It's not, but it is displaying what scientists call tonic immobility, a fear-potentiated response. It's thought that the chicken believes its life is in danger due to the unfamiliar stress of being restrained and held to the ground. Focusing the chicken's attention in this way while pinning it down sends the chicken into a catatonic state. Animals such as ducks, sharks, snakes and rabbits all display this behaviour to avoid predators, almost like playing dead.

Hypnosis has been used during a wide range of surgeries, including a caesarean birth

## Under the knife

Although it's safe to say we're unlikely to see open-heart surgeries carried out solely with hypnotic pain alleviation, there are plenty of examples of hypnosis managing pain during less invasive procedures. In 2014, a Guinean singer based in Paris underwent surgery to remove a parathyroid gland tumour from her throat. Although this wasn't a life-threatening condition, without treatment the singer's career may have come to an end. A world first at the time, Kante underwent the surgery without anaesthesia and entered a hypnotic trance-like state. This would allow her to sing during the critical moments of the surgery so that the surgeons could make sure that they did not damage her vocal cords. The surgery was a success, while Kante was blissfully unaware as she envisioned far-away Senegal.

# Could you be hypnotised?

*As an assistant professor of psychology at Harvard University and the author of The Pregnant Man and Other Cases from a Hypnotherapist's Couch, Deirdre Barrett gives us an insight into the benefits of hypnosis*

**Are there any particular factors that determine whether a person is more or less susceptible to hypnosis?**

Yes. There's a little bit of research that suggests it may have some biological element. Identical twins seem to have some correlation between their hypnotic susceptibility. We certainly think that a lot of it is learned behaviour or just variables that we don't completely understand. Susceptibility or absorption – meaning absorption in imaginative involvement – questionnaires are the best predictors. They are basically questions that have to do with experiencing informal trance-like phenomena at other times, such as did you ever have an imaginary companion as a child? When you imagine something, can you picture it very vividly? When you are focused on reading a novel, does someone have to call your name much more loudly or repeatedly before you hear them? It's about vivid imagination and about tuning out the real environment or sometimes experiencing physiologic sensations such as queasiness, cold or hotness as somebody suggests them or you're looking at a visual stimulus about them. That sort of scale predicts response to a formal hypnotic induction quite well. People may not realise quite how much they can do this, but in a sense they're already tending to do that sort of thing to informal suggestions, and the ability is manifesting itself in everyday life in milder ways.

**Why do people forget what's happened during the time they are hypnotised?**

Most people do remember what's happened. If the hypnotist suggests that you will not remember anything, the average person will remember. It's people in the top ten per cent of hypnotisability that are able to have suggested amnesia. It's an even smaller group that seems to have spontaneous amnesia, and of those you can hypnotise a person and suggest that they'll now recall what happened. Then there are a few people that just never recall, and yet presumably something was registering. People sometimes have psychologically caused amnesia to very traumatic sudden events. There are psychological disorders in which people don't remember certain kinds of material, so it's something that the human brain is capable of, but that we don't usually have on-demand control over.

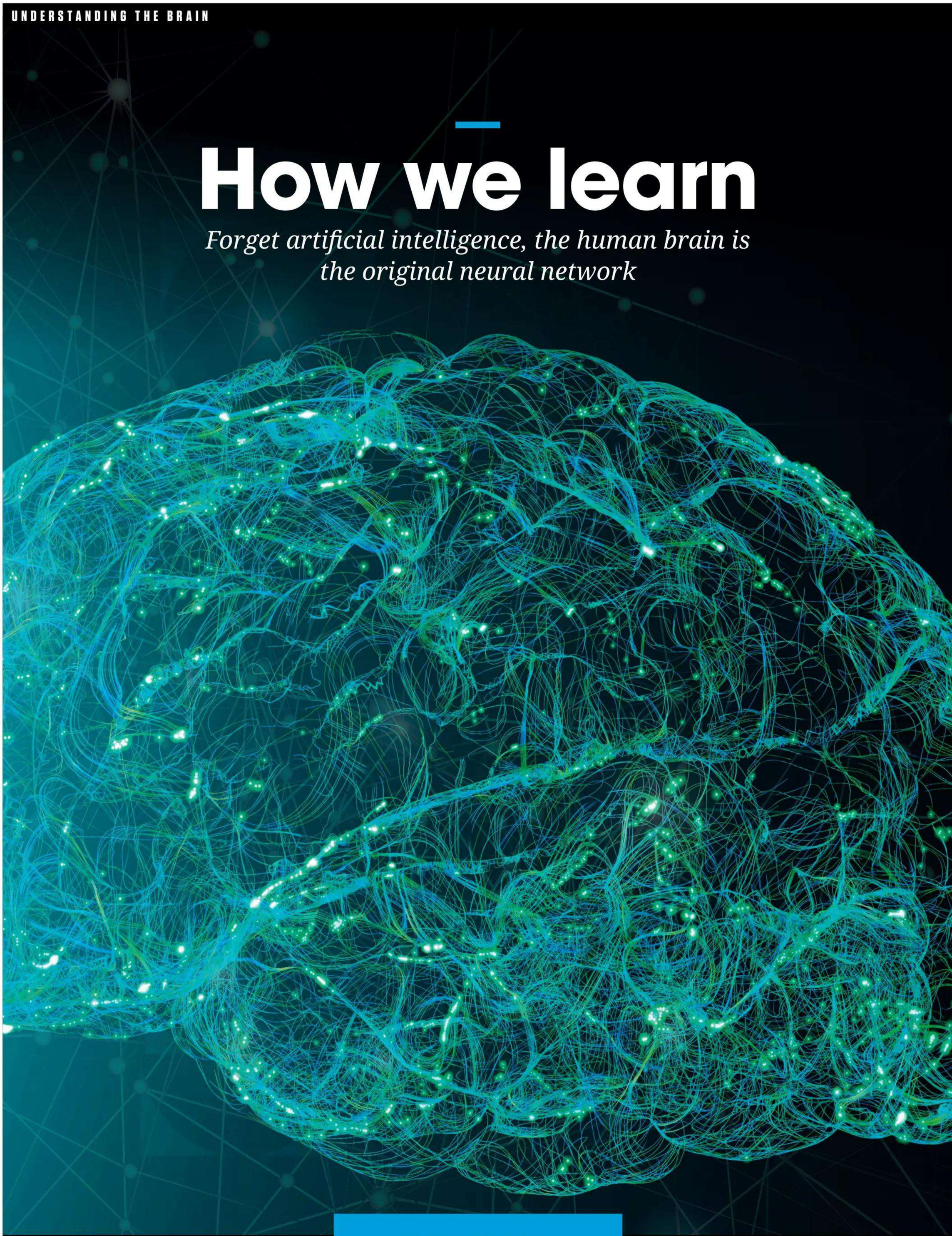
**How effective is hypnosis in treating lifelong behavioural issues such as smoking?**

Hypnosis is a really dramatically effective treatment for people who are highly hypnotisable. It's really having no more than a bit of a placebo effect for people of low hypnotisability. For things like habit changes, there are two things that predict how well the treatment will go, and one of them is how hypnotisable the person is, but also motivation, how badly the person wants to quit, how willing they are to apply willpower to this. There may be some people who go into a very light trance and only get a bit of help in resisting urges to smoke, but are nevertheless very motivated in the general sense, who will then quit smoking. However, for the high hypnotisables you really get to tune out the physiologic withdrawal. Just like with pain control, it doesn't do anything dramatic for most people, but you can tune out extreme pain if you're a high hypnotisable. I have worked with and seen high-hypnotisable patients who were lifelong smokers who after one session just said they had no desire to smoke. They reported disgust at cigarettes and no cravings.

© Alamy / Getty / Deirdre Barrett

# How we learn

*Forget artificial intelligence, the human brain is the original neural network*



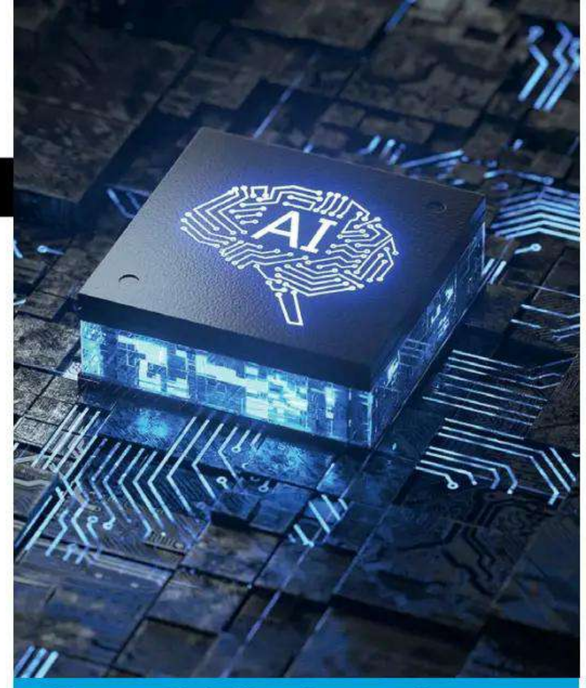
PSYCHOLOGY

The brain is a collection of an estimated 86 billion neurons, connected together in a communications network more complex than the internet. Neurons pass messages like telephone wires, shooting electrical impulses at speeds of up to 180 miles per hour. They exchange signals using packets of chemicals called neurotransmitters, which can either tell the next neuron to pass the message along or to stay quiet. The connections between neurons are the basis of memory, and making them is how we learn.

The theory of human learning is founded on the idea that one brain cell can't learn on its own – it's the connections between brain cells that make learning possible. In the late 1940s, psychologist Donald Hebb explained that "nerves that fire together wire together". This essentially means that when brain cells are repeatedly activated at the same time, they become physically and chemically linked. Learning a new skill is all about strengthening the connections between the brain cells that send the signals to perform that skill.

This concept is called 'Hebbian learning', and at a cellular level, it looks a bit like this: when one brain cell sends a message to another brain cell, the second cell has to decide whether to pass the message along. At first it's not always clear if the message is important, but if the cell sends the same message again and again and again, something starts to change. The first cell starts producing more neurotransmitters so that it can send a bigger signal, and the second cell makes more receptors so that it can detect the signal more easily. Together these changes strengthen the connection between the cells, ensuring that the message always gets through.

In the real brain, the situation is a bit more complicated. It's rare that communication happens only between two cells. In reality, each neuron



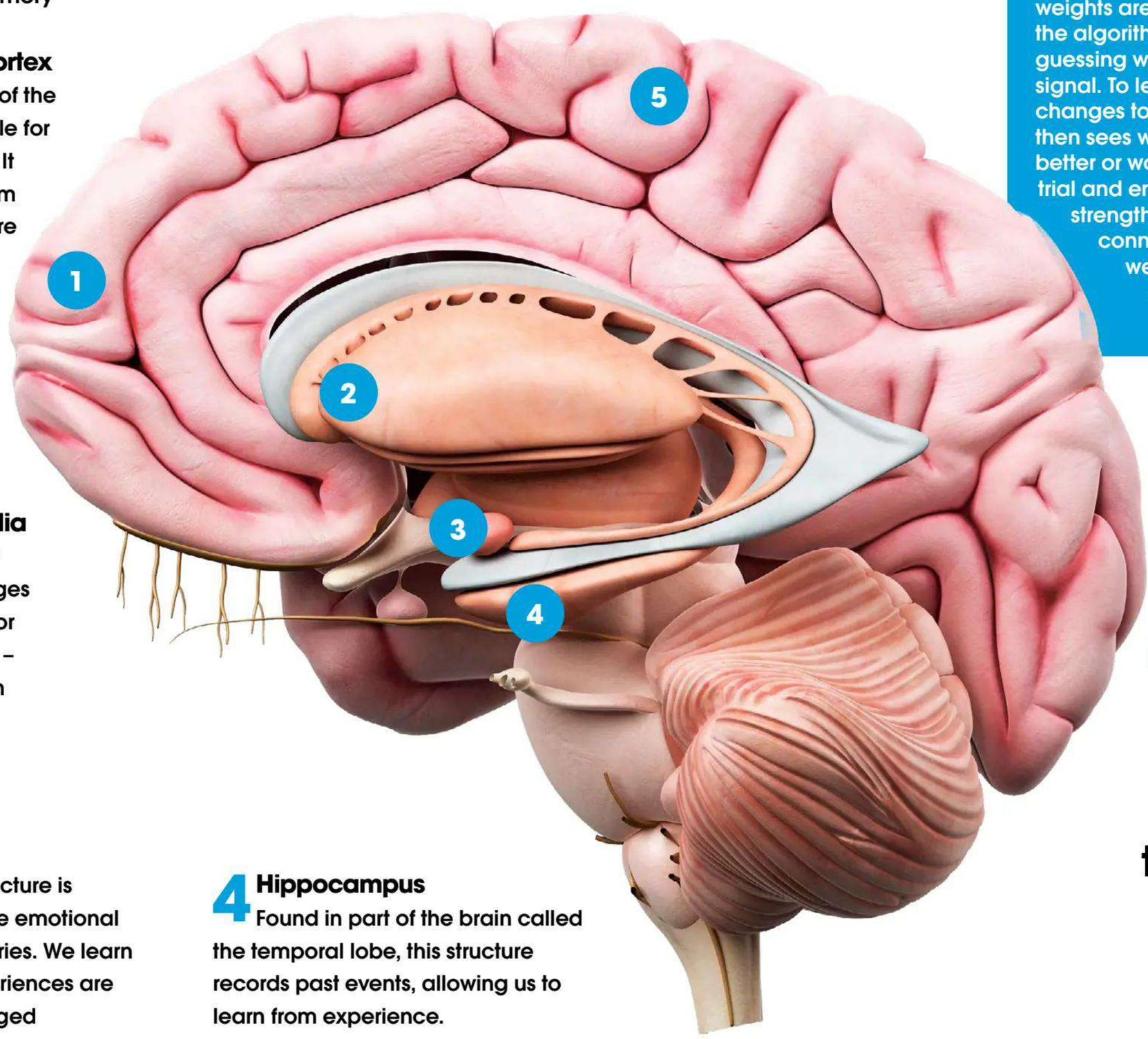

The most intelligent computer algorithms are modelled on the human brain

## Artificial neural networks

AI works in almost the same way as the human brain. Instead of thousands of brain cells, machine learning algorithms have thousands of nodes. Just like a neuron, each node receives incoming signals and has to decide whether to pass them on to the next node. To make this choice, it gives each signal a weight, which determines how important it is. A higher weight means a higher chance the signal will be passed on. To begin with all the weights are set at random, so the algorithm is essentially guessing what to do with each signal. To learn, it makes tiny changes to the weights, and then sees whether its guess is better or worse than before. This trial and error tunes the network, strengthening good connections and weakening bad ones – exactly like in human learning.

## The brain's learning centres

These five brain areas are essential for learning and memory




**1 Prefrontal cortex**
The very front of the brain is responsible for working memory. It provides short-term storage while we're learning.

**2 Basal ganglia**
This cluster of brain cells manages motor learning – or 'muscle memory' – and the formation of habits.

**3 Amygdala**
This small structure is responsible for the emotional content of memories. We learn better when experiences are emotionally charged

**4 Hippocampus**
Found in part of the brain called the temporal lobe, this structure records past events, allowing us to learn from experience.

**5 Neocortex**
This is the brain's main storage bank. The hippocampus transfers learning to the neocortex while we're sleeping.

**"The theory of human learning is founded on the idea one brain cell can't learn on its own"**

© Getty

**Neurotransmitter**
Chemical messages pass signals from one neuron to the next. After learning, the amount of these each neuron releases goes up.

**Neuron**
Neurons send messages across the brain by passing electrical signals down long, thin structures called axons.

**Receptors**
Receptors detect the neurotransmitters released by other neurons and trigger fresh electrical impulses. After learning, their numbers also increase.

**Synapse**
Neurons pass signals to other neurons by sending chemicals called neurotransmitters across microscopic gaps.

# Tuning the brain's connections

On a microscopic level, learning is all about the connections between brain cells

**Oligodendrocyte**
These fatty cells wind around the axons of nerve cells like the plastic around electrical wires.

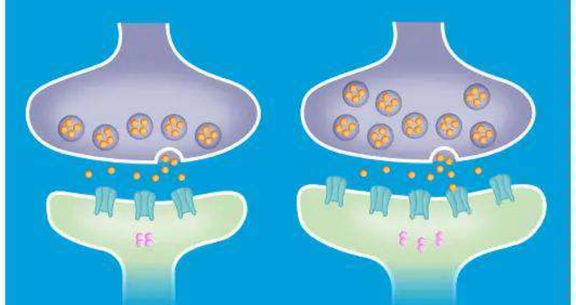
**Myelin sheath**
Wraps of myelin insulate the electrical signals passing along axons, allowing them to travel faster and without interference.

**Astrocyte**
Star-shaped support cells tune the speed of communication by controlling the thickness of the insulation around each neuron.

**Sheath thickening**
During learning, cells called oligodendrocytes coat nerve cells in extra myelin, increasing the speed of nerve conduction.

## Learning on a molecular scale

Signals pass from one neuron to another across microscopic gaps called synapses. The first neuron releases small packets of chemicals called neurotransmitters, which cross the gap and hit the second neuron. Receptors on the second neuron detect the neurotransmitters, and if the signal is strong enough, they trigger a fresh electrical impulse. Learning increases the neurotransmitters the first neuron releases, and boosts the number of neurotransmitter receptors on the second neuron. These changes strengthen the connection between the cells, making it easier for them to exchange signals in the future.



makes up to 1,000 connections to others, and signals can arrive all at once. Each neuron has to weigh up every message it receives and decide whether to pass it along. Learning is the process of balancing those decisions. One of the easiest ways to see this in action is to look at organisms with simpler nervous systems than our own.

Sea slugs have an organ called a siphon, which they use for moving, feeding and breathing. It's quite delicate, so if they sense danger they quickly pull it away. This reflex normally doesn't happen if they feel a really gentle touch on their siphon. But they can learn to withdraw from this non-threatening situation if the connections between their neurons are altered.

> **"Each neuron makes up to 1,000 connections to others"**

Researchers at the University of California attached electrodes to sea slug neurons. They chose one neuron from the siphon and another from the tail, both of which pass messages to a third neuron that controls siphon movement. Before the experiment, the

Adults find it easier to learn skills related to skills they have already mastered

## From zero to hero

Invented by Noel Burch in the 1970s, the four stages of competence explain how we think and learn

**1 Unconscious incompetence**
The learner is completely unaware that they lack the skill, and may even be overconfident in their ability.

**2 Conscious incompetence**
The learner becomes aware that there is a gap in their understanding. This can either be motivating or demoralising.

**3 Conscious competence**
The learner practises the skill and starts to learn, but they need to concentrate hard to be successful.

**4 Unconscious competence**
The learner masters the skill. They are now so good at it that they can do it without thinking.

movement neuron didn't really respond to messages from the siphon neuron.

To change this, the researchers passed electrical impulses along the siphon neuron to simulate a gentle touch. At the same time they passed strong electrical impulses along the tail neuron to simulate a danger signal. This taught the synapse that the gentle touch signal meant that danger might soon be coming. During the experiment, the connection between the siphon neuron and the movement neuron strengthened so much that eventually a light touch on its own was enough to trigger the withdrawal reflex without any danger signal from the tail at all.

Without school learning, knowledge wouldn't be gained as quickly

## 5 facts about your neurons

### 1 They have three parts

The cell body houses genetic code and protein factories. Dendrites receive incoming signals, and the axon passes electrical messages to other cells.

### 2 There are three types

Sensory neurons detect touch, taste, light, sound and smell. Motor neurons send signals to the muscles and interneurons connect other neurons together.

### 3 They don't live forever

Like us, nerve cells in the brain and body get old and die. Loss of neurons contributes to diseases such as Alzheimer's, Parkinson's and Huntington's.

### 4 They need support

Neurons rely on other cells to do their job properly. Astrocytes maintain chemical balance, oligodendrocytes insulate electrical signals and microglia guard against infection.

### 5 They can regenerate

Researchers once thought brain cell regeneration was impossible. Now we know that even in adults there are stem cells capable of creating new neurons.

© Getty / Science Photo Library

# Human, machine and evolutionary learning

*Dr Richard Watson is an associate professor at the University of Southampton. He works at the interface between computer science and theoretical evolutionary biology*

Just because we're made out of different stuff doesn't mean that humans learn in a different way to computers. Dr Watson's work on expanding the theory of evolution has given him great insight into the way animals, machines and even evolution itself learns and adapts – and he has come to some quite staggering conclusions.

**Can you explain how learning works?**
One of the key insights of neural models of brain learning is that intelligence is not in the neurons – it's in the organisation of the connections between them. The way that they learn is by changing the strengths of these connections. There's one particular model of how connections change which is sufficient to do some really interesting behaviours, and that is Hebbian learning. It says that if two neurons fire at the same time, or in quick succession, then the strength of the connection between them is increased. But if one fires without the other, the connection is decreased.

That's such a simple rule, but it's capable of many interesting behaviours: forming an associative memory – storing multiple patterns that describe what things naturally 'go together' – generalising from past data to new situations and improving its ability to solve problems with experience.

**Is that the same as the way AI learns?**
Artificial neural networks also learn by changing the strength of the connections between neurons. The way that they change the strength of the connections is not the same in the details, but it's similar in essence.

In machine learning you often have an idea of what the output is supposed to be. If it's a picture of a cat, you want it to say 'cat'. If a network's output is a little bit wrong, you adjust the connections in the direction that makes it a little bit less wrong. Hebb's rule reinforces what your response was already, whereas this rule makes your response more like what the answer 'should' be – but they both work by modifying connection strengths.

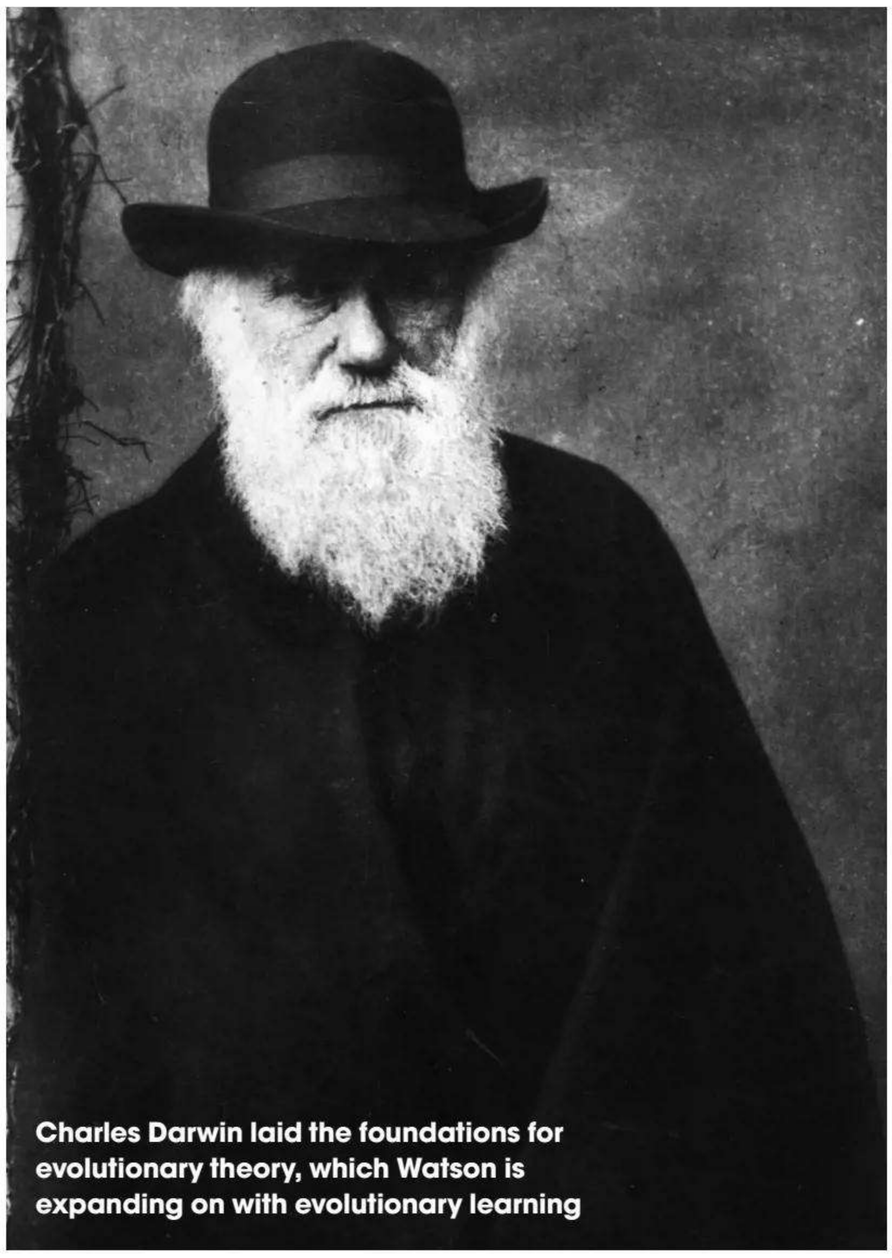
**Watson participated in the world's largest project to update our understanding of evolution**

**Your work suggests that evolution can learn too. What does that mean?**
The kind of learning where you learn by changing the strengths of connections, natural selection can do that too. Evolution works by making small random changes. If the change produces an improvement then it's kept, and if it makes things worse then it's not. That sounds a bit like trial-and-error learning: you try stuff at random and do more of the behaviours that work and less of the behaviours that don't. That kind of equivalence between learning and evolution has been noted many times.
A further level of equivalence is a connection between evolution and the kind of connection-based learning that I mentioned already. If you produce an organism with not just a set of genes, but a network of genes, then the effect of natural selection acting on the connections between the genes acts in the same way that Hebb's rule did in the previous examples. It strengthens the connections between genes that are expressed at the same time, and it weakens the connections between genes where one is expressed and the other is not.

It means that evolution by natural selection can do the same kind of tricks that neural networks can do. It can evolve a network that holds an associative memory of multiple patterns it's been exposed to in the past. It can improve its ability to solve problems with experience in the same way that a neural network can. And it can generalise; evolution isn't supposed to be able to anticipate which phenotypes will be well adapted for a new environment. A neural network can do that: you train it on past data and you show it a situation it hasn't seen before, and it produces an output suitable for that new situation. And that's not magic – it's called generalisation. The idea that evolution can do that too expands our understanding of how evolution works.

**What do the links between human learning, AI and evolution tell us?**
These principles of learning can also operate in other kinds of networks that are not brains and not networks within organisms. Networks such as the networks of friendships between people in a society.

Suppose that I'm doing some behaviour and you're doing some behaviour. When I behave the same as you, we strengthen our friendship. And



Charles Darwin laid the foundations for evolutionary theory, which Watson is expanding on with evolutionary learning

An AI cat at the China International Big Data Industry Expo in 2021. This robot learns in a similar way to the girl next to it

## "Artificial neural networks also learn by changing the strength of the connections"

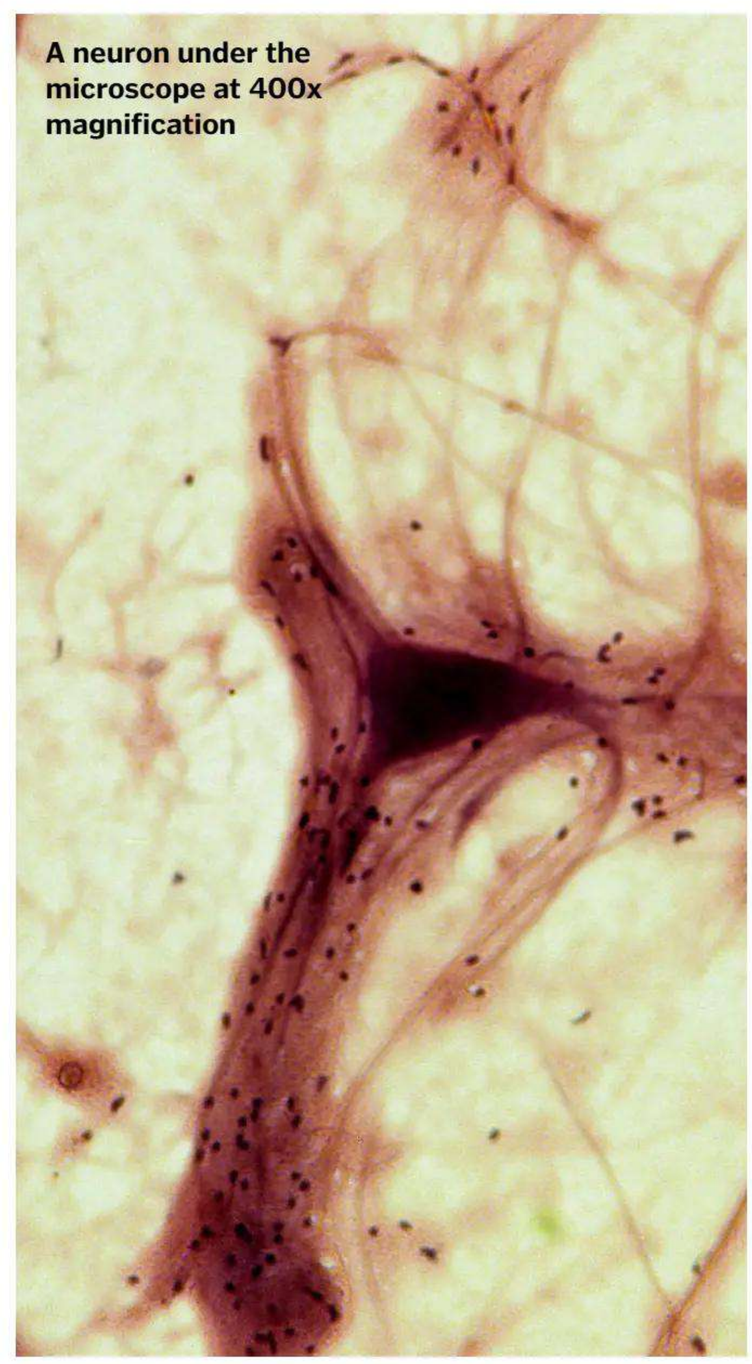
when I do the opposite of what you're doing, we weaken our friendship. If friendships change in that way, then that means that social networks can do the same kind of learning that neural networks and gene networks can do.
It means that human organisations and human society can learn in a way that's greater than the sum of the parts – a way that's not just about getting smarter because the people in the system get smarter, but about intelligence that's held in the relationships between people.

**What do you think that means for the future?**
The conventional scientific view suggests that survival of the fittest is how nature works. If you interfere with competition, you'll make the system worse, not better. This supports a worldview that says that life is about competition, selfishness and individualism.

But there's a different worldview that says we're all part of a larger web of living things in relationships with one another. That worldview is more to do with cooperation and connectedness, not winning.

If it's the case that selection changes relationships in a way that produces intelligence at the system level, then it's not just everyone against everyone fighting for themselves. Although they might not know what their role is in the system, they are part of a larger system, and the organisation of that system is not arbitrary. The organisation of that system is shaped by the past experience of the system and has knowledge in it which is valuable, knowledge which enables the system to adapt to future circumstances.

This gives some scientific basis to the ancient worldview that we're part of a harmonious web of life with relationships that deserve respect. That's where the systemic intelligence resides – not in us as individuals, but in the connections between us and with other living things. This is a more humble view where treating other people and the biosphere as resources to be exploited is not natural, not healthy and not inevitable.

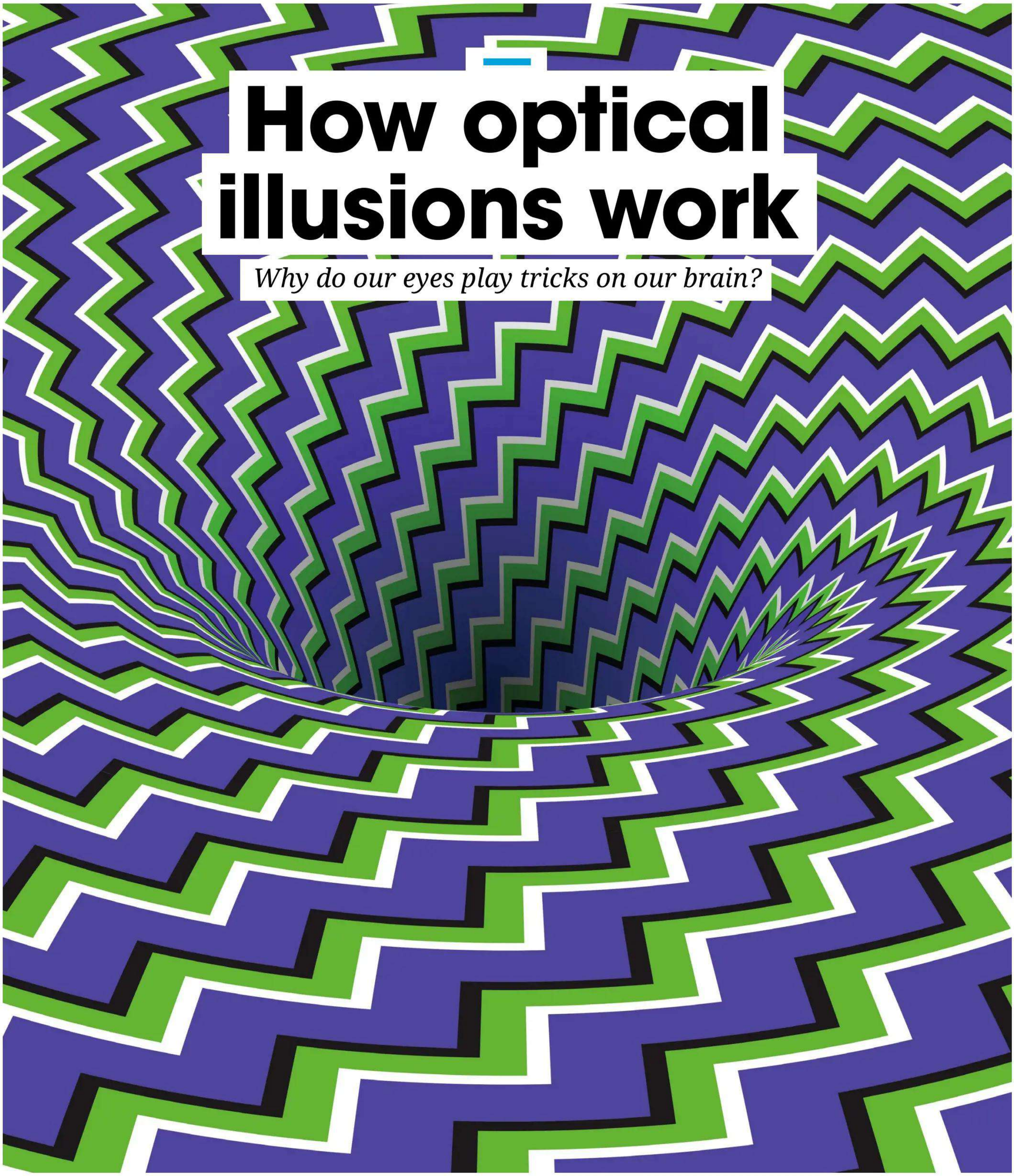


A neuron under the microscope at 400x magnification

© Sarah Rush / Alamy / Getty

# How optical illusions work

*Why do our eyes play tricks on our brain?*



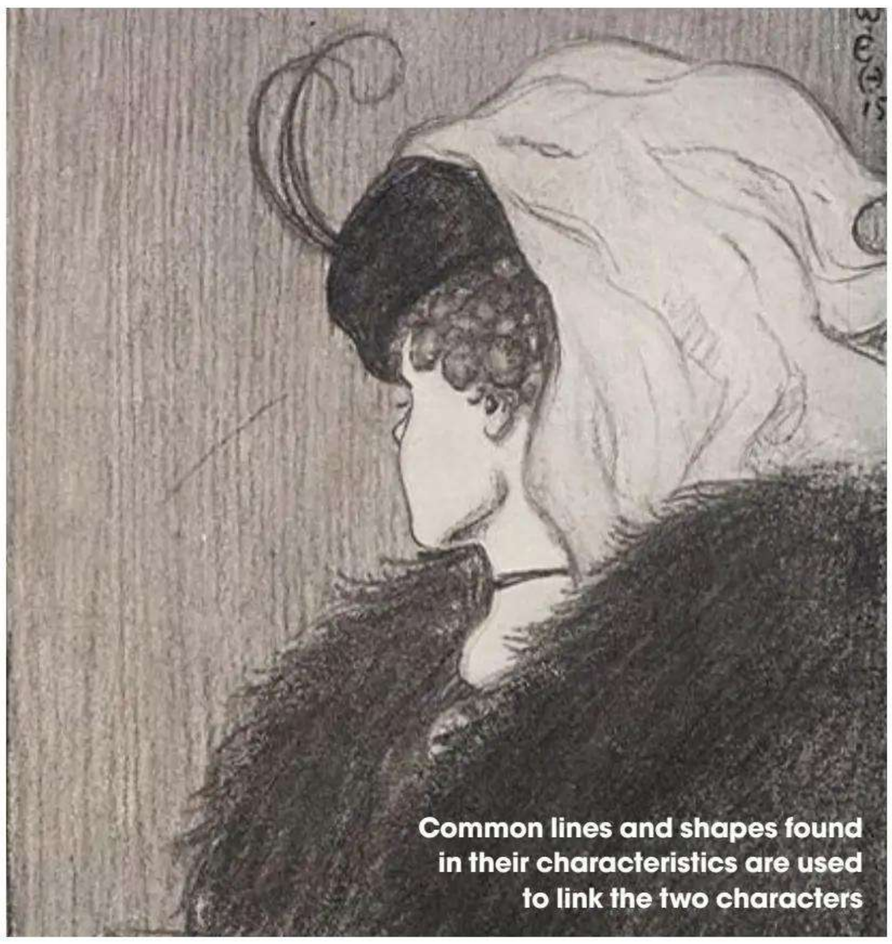
PSYCHOLOGY

Some people say that seeing is believing. We expect what we see to exist. When we look at what's in front of our eyes, each scene comes with masses of information. What do the shapes mean and how do they connect? To make sense of the world around us, we rely on our eyes to provide our brains with accurate visual information – but sometimes our eyes can deceive us. Optical illusions make you see things which aren't physically there, give motion to shapes that are static and can even make something impossible seem real. Split into three main categories – literal, physiological and cognitive – each has a distinctive way of producing these mystical marvels. Not merely entertaining out-of-the-ordinary spectacles, visual illusions provide insight into the science of eye-brain interactions.

Many need to be approached with some existing knowledge. Take the title of this article as an example. You would have known immediately that you were reading about optical illusions. But how? Illusions can be incorporated into text as well as images. To someone unfamiliar with the shape of letters or the English alphabet, these blocks and shapes would hold no other meaning. For your brain to receive the information, it analysed the shapes and compared them to the knowledge stored in your memory, reading the shapes as letters. Focusing your attention solely on the blocks themselves would leave you with a meaningless pattern. The following illusions will put your eyes and brain to the test. What will your brain be able to comprehend and how will your eyes throw it off track?

# Literal optical illusions

*These creations have more than one reality*



Common lines and shapes found in their characteristics are used to link the two characters

## How your brain is tricked

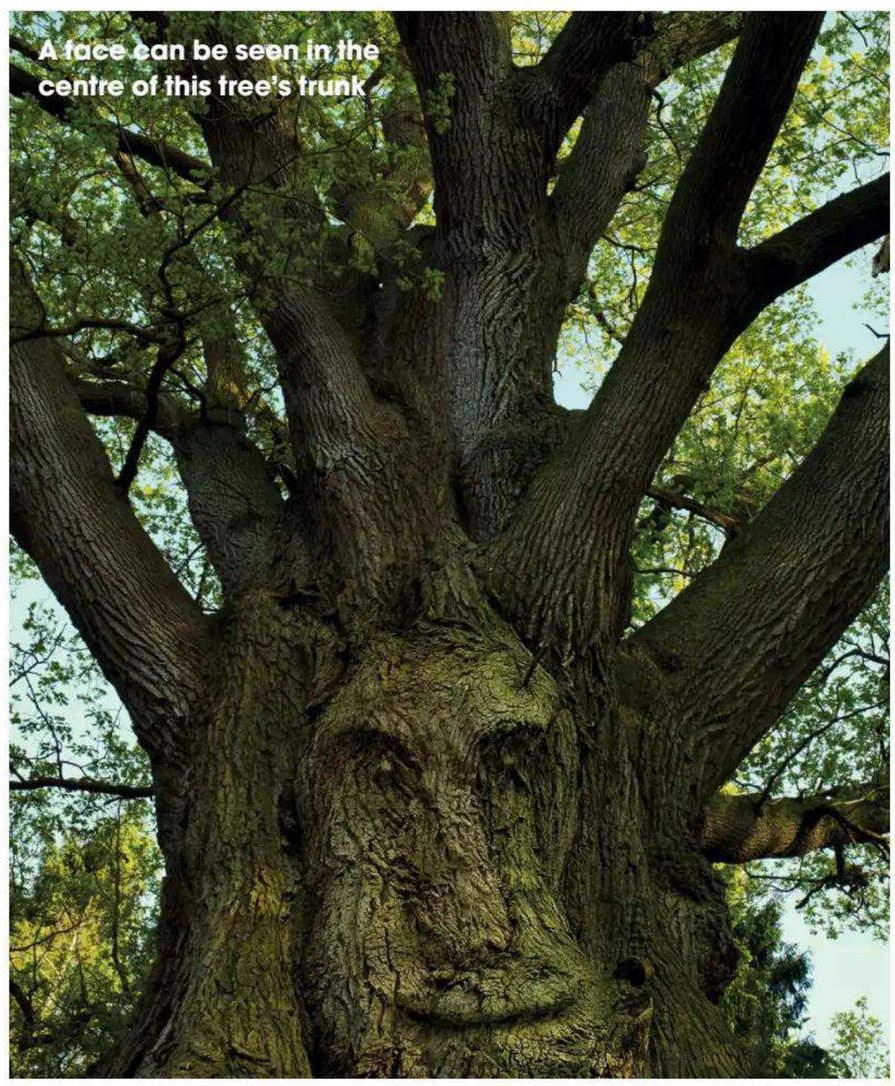
When you look at this work of art, you will notice a person. But what does that person look like? Entitled 'My Wife and my Mother-in-Law', this drawing by American cartoonist William Ely Hill captures both the characters in its title at once. Depending on which section your eyes examine first, you will either be drawn to the young or old woman.

Some psychologists have concluded that if you are younger you are more likely to notice the young woman first, while if you are older you will notice the old, possibly due to people spending more time around others close in age. When your brain is trying to quickly make sense of what you are viewing, it will create familiar shapes and objects, and the woman in that category will be seen first.

If you are still struggling to work out where the other woman is, the old woman's mouth doubles up as the young woman's necklace, while the young woman's chin and jawline make up the old woman's large, pointy nose.

## Hidden faces

Deception isn't always carefully planned. Sometimes nature and the everyday muddle your brain too. Nature's unique shapes and forms can cause you to find new and unusual variations around every unexplored corner. Within the bark of this tree, the growths and dents reveal an imposter. Immediately your eyes are drawn to the shape of a face at the centre, highlighted by the light covering of moss. Your brain is familiar with the form of a human face, as you are likely to see many of them as you go about each day. When presented with this tree, while it is only a tree and not literally a face, your brain recognises both, and it will struggle not to see this familiar fat-lipped figure every time you glance back.



A face can be seen in the centre of this tree's trunk

## Stare out

**1 Observe image**
When you're presented with the image, your eyes will quickly scan it, relaying this visual information to your brain.

**2 Analyse sections**
The brain then chooses which section and shapes to focus on. This choice will determine how you perceive the image.

**3 Process shape**
Your memory stores shapes the brain has encountered. It compares these with the shapes analysed to find objects in the image.

**4 Produce picture**
Objects and shapes are pieced together to create your initial version of the double image.

**5 Quick result**
We are quick to make our first judgement of the illusion, as fast interpretation of visual information helps humans to survive.

© Getty / Wiki: William Ely Hill

# Physiological optical illusions

*Images that perform physical transformations*

## Stare out

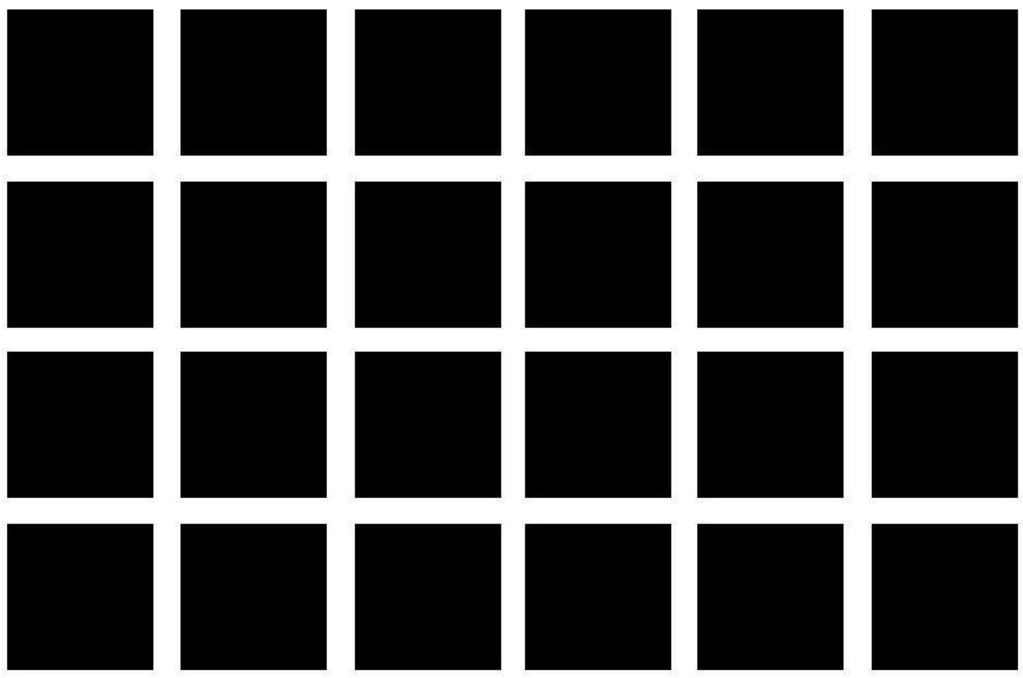
**1 Observe image**
When presented with the image, your eyes relay visual information to the brain. You see the colour, brightness and position of the image's components.

**2 Fix target**
Some physiological illusions require you to fixate on one target for a long period, while in others this is simply the area you first happen to glance at.

**3 Receptor reaction**
Cells at the back of the eye absorb the light photons from the image. Light at the centre of vision, as well as the colour white and bright light, provide the highest stimulation.

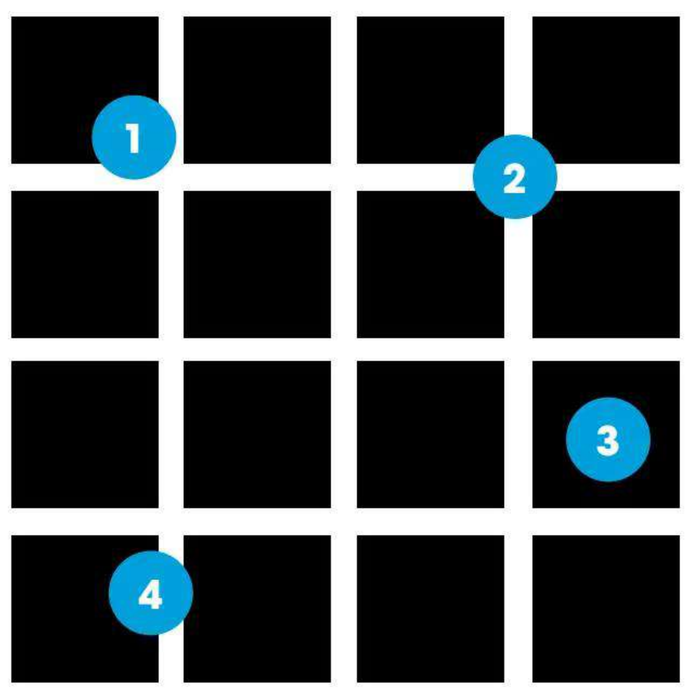
**4 Changing gaze**
As you move your eyes to target a new area of the image, these illusions begin. Different photoreceptors are being stimulated as new light and shapes are exposed.

**5 Altered image**
Physiological illusions create a change in brightness, movement, colour or tilt. As your eyes take in new elements of these images, previously clear sections can then become confused in position or tone.



## Disappearing dots

A Hermann grid is a famous optical illusion leaving the observer playing an impossible game of chase the dots. Scan your eyes over these black squares and take notice of the areas where the white lines cross. Can you see grey dots in your peripheral vision? Though they are scattered across the intersecting lines, as you focus on a single dot you will witness it disappearing. These dots were never really there, but made up by your eyes.

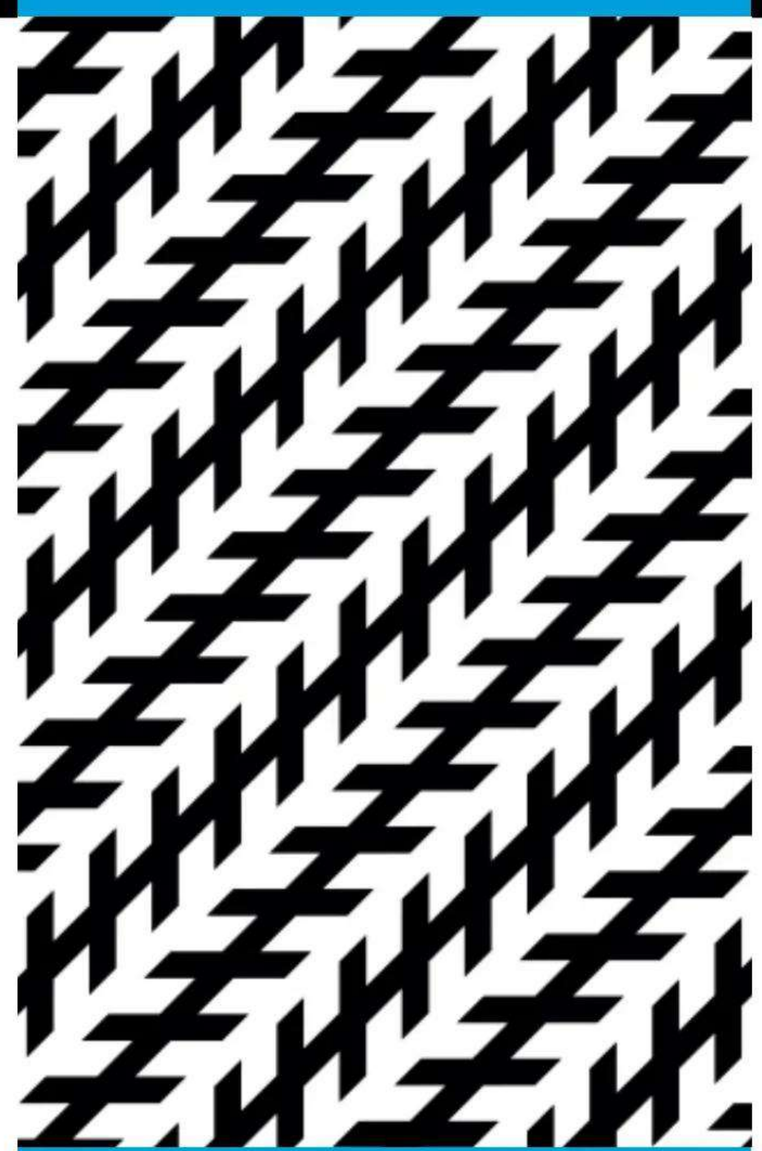



**1 Contrast**
The circles you see appearing and disappearing between the squares are due to the difference in lightness between the black and white areas. These dots are grey in colour, a combination of the contrasting tones.

**2 Focus**
When looking directly at one, the dot disappears. This is because the photoreceptors in the centre of your eye are sharp and clear. Darker squares are less able to inhibit the bright centre.

**3 Solid block**
No matter where your eyes rest on the grid, the black squares are always interpreted by your eyes as black since these areas have no surrounding exposure to light.

**4 Peripheral issues**
When parts of the image enter your peripheral vision, they become less accurate. The brain is filling in the gaps left by our eyes' limited field of view. It perceives the white intersections with protruding black corners as grey.

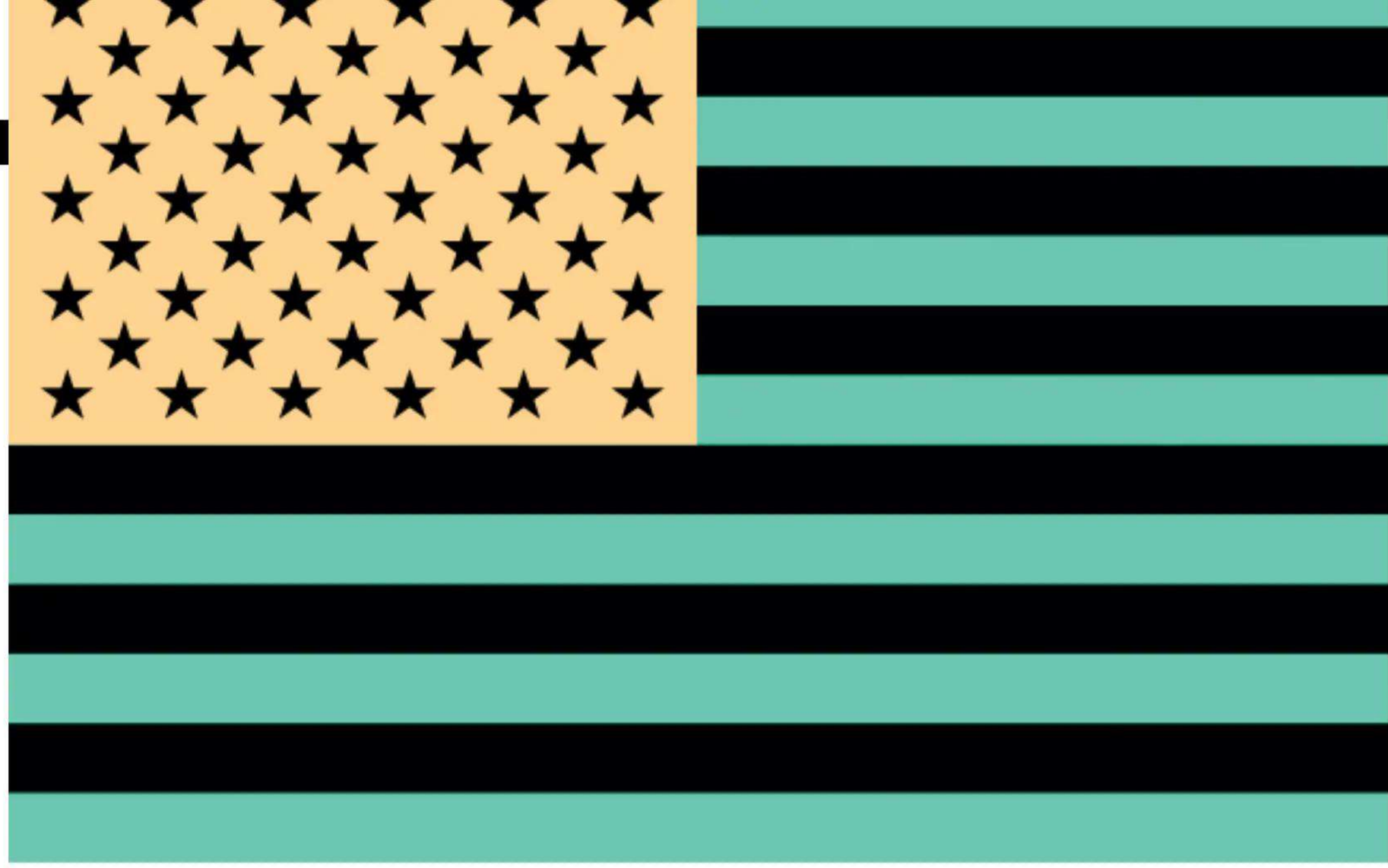


These long lines actually run parallel to each other

## Leaning lines

Do you think that the long black lines in this image are parallel to one another? Do they all travel in the same direction or are they tilting different ways? This illusion is all down to the multiple short lines intersecting the long ones. While the long diagonal lines appear to tilt in different directions, they actually all cross the picture at exactly the same angle.

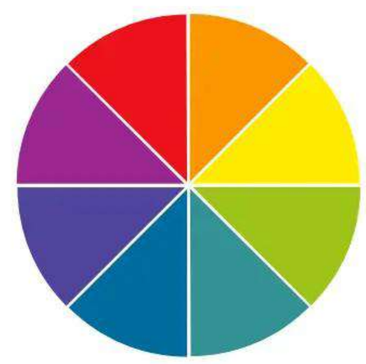
How can the addition of these smaller lines distort the picture so drastically? The science behind this illusion is all about how the brain processes the angle of an image. One theory is that our brains tend to perceive small acute angles as being smaller than they really are, while we also overestimate the size of larger obtuse angles. In distorting the angle created between the long and short lines, the edges of the longer lines become warped in our heads. Each long line appears to tilt in the direction of the smaller angle. These angles are more likely to be misinterpreted when viewed on lines that are neither horizontal nor vertical, which is why they are positioned diagonally.



## Colour correction

This version of the American flag has the right patterns and shapes, but wildly wrong colours. Green, orange and black have been used in place of red, blue and white. These may seem like randomly selected colours, but what if you were able to see the true-coloured flag through this image?

To make sure you're able to find the image's hidden flag you will need to first scan the code with any smart device to view it on a bright screen. When you have your flag ready, begin by focusing on the bottom-right corner of the rectangle of stars. Stare at this section for at least 30 seconds without averting your gaze, then look away from the image and look at a plain surface such as the wall or a piece of paper. Can you see an after image? Blinking may help you find the flag.



Colours opposite each other on a colour wheel are complementary

## Stare out

**1 Colour selection**
Green and orange appear to have no link with the design, but when observing a colour wheel you'll see the tones are carefully selected. Facing green lies red, while facing orange is blue. This makes them opposite colours.

**2 Stare out**
Specific colour receptors in your eyes are stimulated based on the tones of the object. As you stare at the colours for an extended period of time, the receptors recognising green and orange become fatigued and less responsive to that colour.

**3 Fresh vision**
As your eyes look away, these receptors are able to rest, stimulating the unused receptors. The opposite colours are produced briefly, which in this case are blue and red.

**4 Background selection**
The plain background helps you to see the afterimage. It remains in your eyes for a while due to the overstimulation caused by staring for a long time at the bright inverted image.

**5 Fade away**
This afterimage illusion will remain for around 30 seconds before your eyes' photoreceptors readjust to normal stimulation.

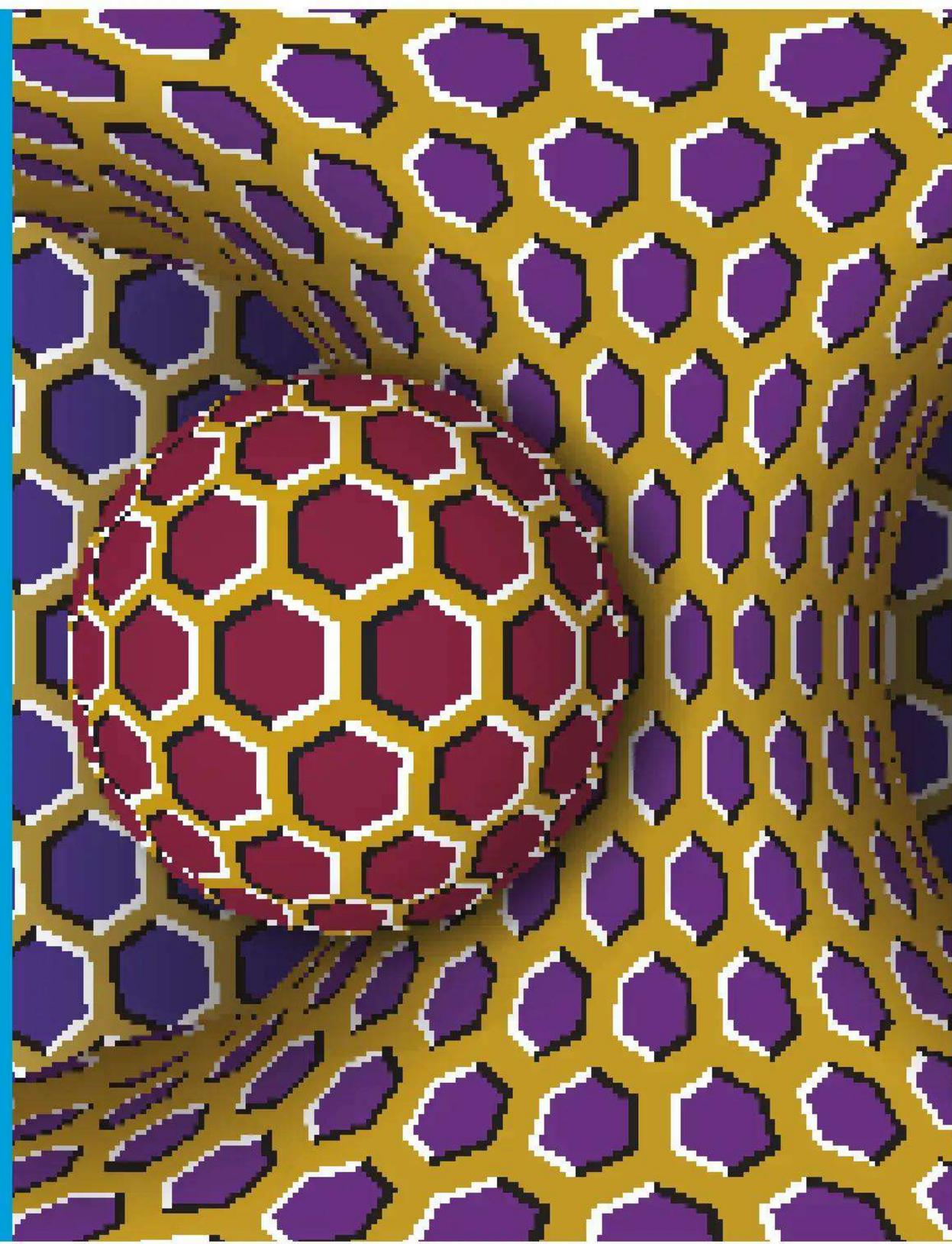
## Dancing imagery

To most people looking at this image, the sphere filled with burgundy-coloured hexagons appears to continuously roll to the right around a purple-hexagon pillar. Created by Yurii Perepadia, a graphic designer and illustrator from Ukraine, the image is an example of illusory motion.

One thing you will notice about this type of physiological optical illusion is that they normally have sections of white incorporated into the pattern. In this case the hexagons which seem to move to the right have white sections lining their right-hand side, while those appearing to move to the left have white lining their left.

Scientists believe that as the lightest shade, white turns our eyes' receptors 'on'. With these light edges positioned next to the contrasting dark edges, photoreceptors bounce between the two images in a flickering sensation, which the brain interprets as motion.

The best way to slow down the motion is to intently stare at one hexagon



© Shutterstock / Wiki Commons: Fibonacci Zoliner

# Cognitive optical illusions

*How are these sights even possible?*

## Stare out

**1 Built knowledge**
Through our experiences, our brains become familiar with the physical world.

**2 Observe image**
When looking at a cognitive illusion, our eyes provide our brains with the visual information to piece together physical objects.

**3 Conflicting facts**
These illusions are designed to create a scenario that is physically impossible. As your brain processes it, you become amazed at seeing something happening that you know cannot.

**4 Acceptance**
There is nothing else the brain can do but accept this conflicting information and be mesmerised by the illusion.

## The never-ending climb

For those who find walking up stairs a chore, this image might be your worst nightmare. Where do these stairs stop? This illusion, known as the Penrose stairs, is designed to hold no start or end point. If you were to try and climb these stairs in real life you would be climbing forever and never reach a higher point.

When taking in this image, your general knowledge of the way stairs and elevation work tells you that stairs cannot operate like this, in a continuous loop. Paradox illusions are designed to show the impossible. While this illusion proves possible on paper, it will only work in its two-dimensional form, with carefully positioned lines to trick the brain.

*Type of cognitive illusion*
**Paradox cognitive illusion**

## Cartoon café

Some illusions can change your perception of what you see and require your brain to switch between interpretations. This café in St Petersburg, Russia, challenges your brain's sense of depth. The black-and-white furniture makes the room look as if it were a 2D sketch. It is the presence of the customers that forces the brain to process the true 3D. Your eyes use shadows and lighting to help see dimensions, but this café is purposely brightly lit to remove these depth giveaways.

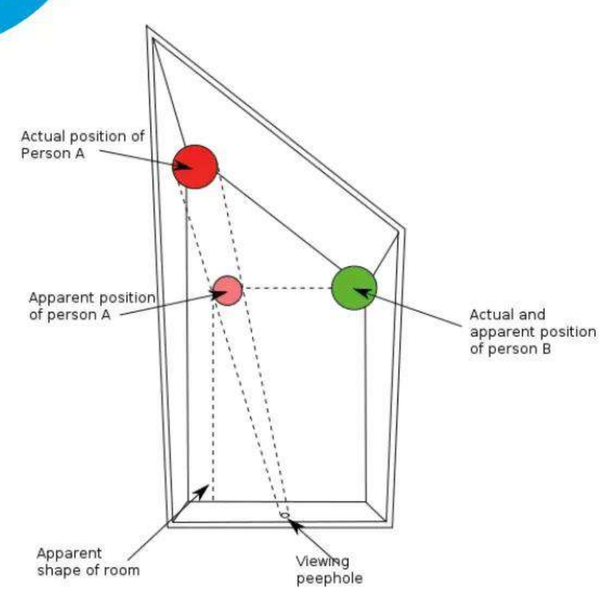
*Type of cognitive illusion*
**Ambiguous cognitive illusion**

**The BWCafe was designed by artist Anfisa Toshina**

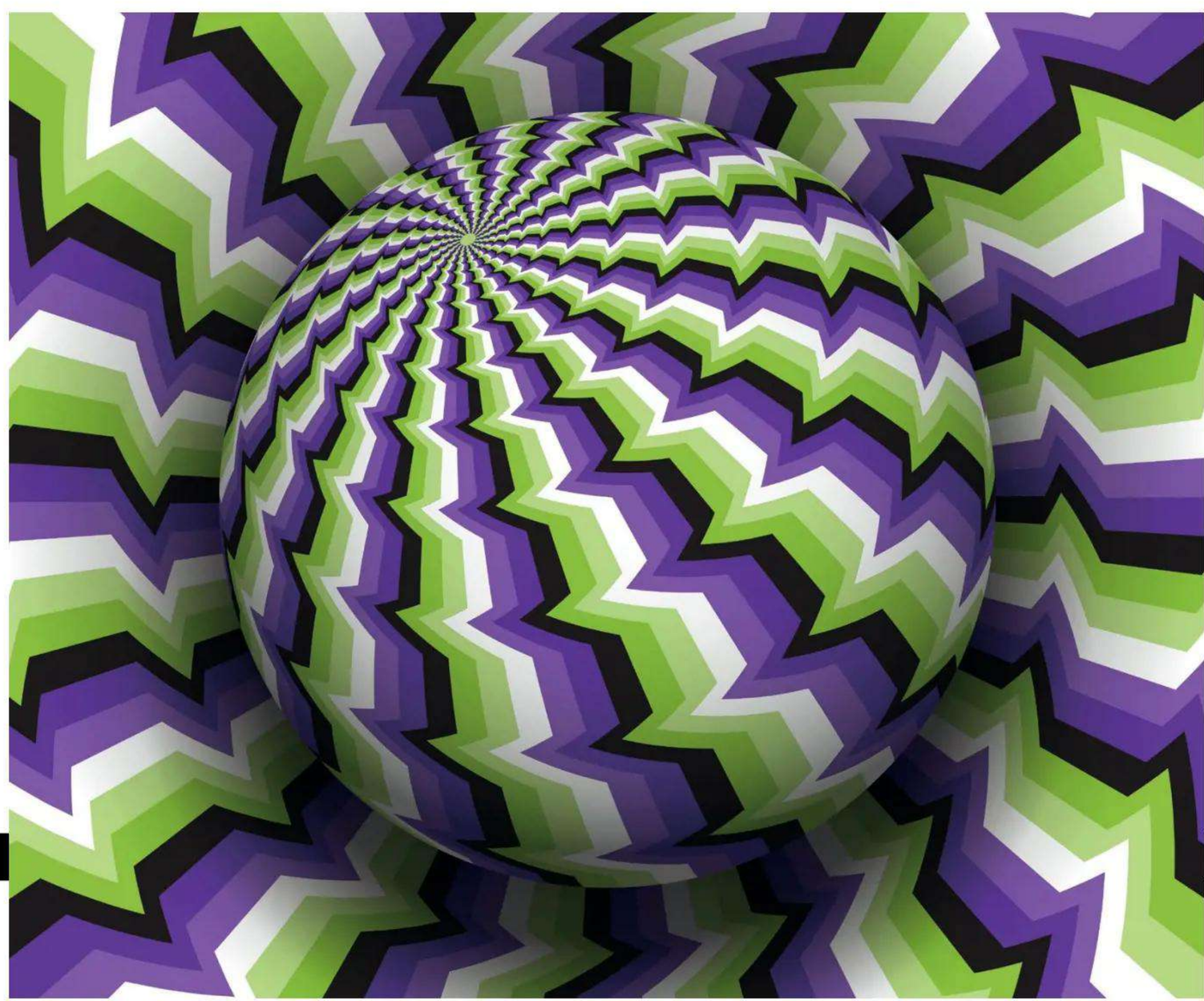
*Type of cognitive illusion*
**Distorting cognitive illusion**

## Extreme size

This is an Ames room, a room where you can appear to tower over your taller friends or shrink to the size of a baby. As an example of a distorting illusion, this room is all about hiding the true shapes and positions from your eyes and brain. When viewed from a specific angle, the room's true dimensions are hidden. Careful detail and artwork is added to make the room appear a regular square shape. When two individuals stand in the far corners, they appear to be standing in line with each other, with one giant person looming over a miniature version of the other. But the floor is not level. The corner where the smaller person stands is at an incline, putting them lower down. Your eyes and brain, used to seeing rectangular rooms, don't notice the slanted walls.




**From the viewing area it doesn't look like the smaller person is further away from you**



## 3D street art

Art is often considered very impressive when the paint on the canvas looks like it could be a photograph. This skill in realistic art allows vivid images to be transferred onto a surface in whichever medium the artist excels in. When hanging up in a gallery this art has a photo-like quality, but when incorporated onto the streets the combination of realistic art and the real world's features have the potential to present optical illusions in the most unexpected locations. This adds interesting images to an otherwise regular street and allows people to engage with the art.

### Walking over a warzone

At Meiji University in Tokyo, Amnesty International used this optical illusion to bring the devastation of war in Syria onto the campus. Walking past this scene, which appeared to lie beneath the concrete floor, made students think about what was happening at an alternative location. By initially confusing the brain into seeing a hidden depth that wasn't really there, it reminded passers-by that although only an illusion to them, to those in Syria this devastation is reality.

### Cycling with a crocodile

Once a year in Almere, Netherlands, artists in the city are allowed to take to the streets and express their talent and quirks. This one, from 2015, uses the angle of lines on the floor to make you see a bike standing up by itself as you approach it. No person has been drawn riding the bike, giving those who are amazed by the illusion the opportunity to take to the saddle for a perfect photo.

© Getty / Wikimedia Commons: Alex Valavanis

# Spirit in the psychology

*Parapsychologist Dr Ciarán O'Keeffe tells us how the mind can affect ghost encounters and a weird experience that even he can't explain*

With over 30 years of experience in the field of parapsychology, Dr O'Keeffe is a leading expert in investigating the paranormal. He has authored several books on paranormal investigation and has appeared on TV's Most Haunted.

**How would you define parapsychology?**
Parapsychology is fundamentally interested in studying extrasensory perception (ESP), which covers three areas: telepathy, clairvoyance and precognition; psychokinesis, which is the action of the mind on an object – the classic example is Uri Geller and his spoon bending; and then the third area is after-death communication or survival after death. This is my area of expertise, and in the world today I would estimate that there's around 100 or so actual parapsychologists qualified to doctorate level, and out of that number you've then got a smaller group, maybe about 10-20 per cent, specifically interested in after-death communication and hauntings.

**How do you explain temperature drops or feeling the presence of a ghost?**
An actual, spontaneous ghostly experiences when you visit a location... there are a number of different experiences you can have. They are all sensory. The most common one is the sense of presence. You walk into a room and you think there's somebody else there with you. The explanations for that could be psychological or environmental. The psychological explanation for that could be down to suggestion. This is an explanation that holds ground for many ghostly experiences. If you walk into a room and we're specifically told that the room is haunted or that the location is haunted, then suggestion kicks in. It's kind of a cultural norm for people to think if there is a ghost, they are either going to see it, which is so rare or they'll feel a presence in some way. There's an interplay that happens between psychology and the environment, too. Imagine you walk into the same room and there is a temperature drop, which suddenly feels very, very calm. Now, that could be down to simple suggestion again, without anything happening, and the temperature remains consistent.
Being told a place is haunted can give you the experience of feeling as though the temperature is dropping. That can be down to the simple 'fight or flight' response. A fearful response to anything can affect your physiology in a particular way. The fearful action to the fact that there might be a ghost in the room is that you want to run. Then, of course, we know physiologically what happens is the blood is redirected into your legs and your body gets ready to run. By doing that, your physiology is changing. The upper part of the body is giving you the perception that your temperature is reduced. But it can be even simpler than that. You could walk into a room and feel a draft or a drop in temperature, and immediately associate that with a ghost because you've been told the room or the location is haunted. Imagine walking into an office and you felt the temperature go down, or a draft – you'd immediately be looking for the window or the air conditioning. You wouldn't be thinking there's a ghost. The drop in temperature could simply be a door or window that's open, but suggestion leads to a misinterpretation of environmental changes. There are examples of people having the sense that they are being touched. That could be down to different reasons, such as suggestion, but also electromagnetic fields. Electromagnetic fields can have observable physical effects, producing sound and problems with electronic kits, but it's both natural and man-made. Particular levels can produce the hallucination of a sense of presence, or a tactile sensation. Infrasound too can play an exacerbating role. Particular levels of infrasound can cause an eye-oscillation effect. It can actually oscillate the eyeball to an extent where you get smearing in the corner of the eye. When you turn around to find out what that dark smearing is in your peripheral vision, you look and it's gone.

Dr O'Keeffe has written books and articles outlining the best ways to investigate the paranormal

**Why do you think people are so willing to accept these experiences as paranormal?**
The most immediate explanation is hope – hope that there is something in the afterlife. If they are having a ghostly experience, then there's evidence of that. I have to say, while that might be the case for some people, I don't think it's the best explanation for why people have these experiences and believe it's a ghost. I think it's a combination of not being aware of natural explanations. The hairs going up on the back of your neck, for example, could be a number of different environmental and psychological reasons. If you've got no knowledge of that, a simple explanation would be ghosts. It's a lot

The spooky experiences some people have in a seance are usually explained by simple human psychology

easier to process what has happened to you with one simple answer, especially if you believe in that sort of thing. There's another aspect to this. Across the country, there are hundreds if not thousands of people going out ghost hunting, it's an incredibly popular pastime. I question whether all of those people are interpreting their experiences as a ghost presence in the hope of an afterlife, or actually if it's some sort of fairground pastime. It's an exciting, adrenaline-fueled experience – to be in a haunted castle or a haunted prison and to think that you could potentially have a ghost experience, to meet a ghost tonight.

**What would you say are explanations for mediums who claim to have contacted spirits?**
The medium may have fraudulently conducted previous research and regurgitated the facts as if it's coming to them paranormally. The other explanation is they may not be aware that they've picked up on that information naturally, as opposed to through prior research. If the location is a National Trust property or English Heritage, for example, where there's information around the location, they may have processed that information but not be fully aware that they've done it. It's almost a form of cryptomnesia, where it's gone into their consciousness but they're not fully aware of it, and they have no memory of how they got the information, passing it off as being paranormal. Another explanation, depending on their accuracy, could be the result of using simple psychological techniques that we know of that are used by pseudo-psychics. Almost like a detective exercise on the medium's part, they start to narrow down the information. Simple statements, such as "I'm getting a gentleman here in the corner, not sure if he's old" – it sounds like a statement but actually had a rising point at the end. It's encouraging anybody in that room who actually knows the information. Then they'll extrapolate more: "This is a father or grandfather and I'm getting a name, a simple name," looking at the reaction of people in the room. People are not concerned about the historical accuracy of it. I've been in investigations where mediums have gone, "I'm getting a very aggressive evil man here called Dave in the corner who used to work here as a cleaner, but then something bad happened with the owner of the location." That's it, nothing historically accurate, and then suddenly you walk into another room and there's people sitting around a Ouija board trying to contact Dave.

> **"Often it doesn't have to be accurate, it's down to people's belief system"**

**Have you ever thought, "Actually, I'm not quite sure how to explain that"?**
There have been a couple of what I call head-scratching moments. There's an example in a nightclub in Birkenhead. The staff and owners of the nightclub reported that the fire exit doors would open of their own accord. Looking at the video footage and having investigated it, you could see that it appears there's no way you can push those doors open from the other side. We even had a chair wedged into the fire exit door so it couldn't open up on its own, but the doors tried to open to the extent that they almost pushed out the chair. At the same location, a group of staff members had been involved in a seance several years prior – a seance they felt kicked off all the phenomena that started in the nightclub, which I'm very sceptical of. But they happened to be at the nightclub the night of our investigation, arriving after they heard we were there. Myself and the other investigator said, "While you're here, would you be interested in replicating that seance just so we can see where people were sat at the table, where the table was, etc.?" I thought that now we had a perfect opportunity to replicate circumstances after which this phenomena happened. We can't replicate the environment, such as humidity levels, air pressure and temperature, but in terms of the physical seating [we could replicate it]. I was observing the seance using a thermal imager, which is a way of assessing relative temperature. I have it set to black and white because a drop in temperature goes green, so it's easy and quick to see a change. After about 20-30 minutes the staff said it didn't feel as though anything's happening. What I didn't tell them was that out of the corners of the room was like a green fog, the temperature was dropping and coming slowly into the room. Over time they began saying that the energy was very strong around them, and during a period of around 20-30 minutes this drop in temperature appeared to surround the seance table. Then one of the ladies said it felt as though the energy was going away. She said that it appeared as though the green fog, this drop in temperature, was just dissipating. It's kind of going away from a central point in the room and then dissipating out of the room. That's an odd thing to happen, a head-scratching moment.

**Dr O'Keeffe was involved in the consultancy and review of the 2012 paranormal movie Red Lights**

© Alamy / Getty

# Escape room psychology

*How unlocking the power of your mind help unlock these puzzle rooms*

Your time starts… now. Trapped in a locked room with just 60 minutes ticking down on the clock, where do you begin in the search for freedom? It might not be a life or death situation, but the unfamiliar surroundings and growing intensity could convince you otherwise. It is this realistic urgency that gets you and your team springing into action in a problem-solving frenzy.

This is an escape room – a live-action game that puts your actions in charge of the outcome. The clues are all around you. You just need to know where to look. Taking on the room puts your brain to the test as you battle against the time pressure, confinement and puzzles of ranging complexity. A good team will be able to work well together, understanding each other's strengths and weaknesses and using them to their advantage. These unique missions give players the opportunity to be the heroes of the event. Everybody goes into these rooms hopeful that their team will be leaving triumphant, but in reality many succumb to the psychological challenges that come with the desperation to escape and beat the challenge.

Being locked in a room may seem like an unusual recreational activity choice, so what is it about this experience that gives us such a thrill? Forced to think quickly, teams usually keep bouncing ideas off each other as they pace around the limited space. This movement in the body and brain has been shown to create a similar effect to going for a walk, as it releases the happy hormone, dopamine. Combined with the adrenaline released during an intense race against time, the energy can be contagious. As it passes through the team, the whole group's mood can be lifted, even in those who fail.

Clues don't always rely on a sharp eye. With thousands of escape rooms multiplying around the world, escape room managers are finding new ways to engage players. Many involve a range of sensory clues that awaken the body and keep different pathways in the brain active.

Above all, escape rooms provide an area to get to know your friends or coworkers better. You may even be playing along with strangers. Finding out how other people's brains work, learning from each other and working as a team to achieve a common goal can give people a sense of purpose, build relationships and hopefully leave people walking away filled with pride and accomplishment.

# Tips for beating the room

### Be comprehensive

It's easy to focus on the biggest, most obvious items but in an escape room the answers won't be handed to you. Search the room thoroughly, checking bookshelves and pockets, or even for secret compartments.

### Keep the whole team aware

If two of your group keep their findings to themselves, it's impossible to discover the answers. The difference between winning and losing is often how quickly items are matched by team members.

### Spread out

If everyone groups around the same puzzle, progress is much more limited. Some people make the mistake of spectating any interesting advancements when there is more that needs to be done. The more tasks that are being worked on, the quicker the escape will be.

### Organisation is key

The brain works better on puzzles when it can see all the elements it is working with. Keep all related objects in one place so they are easy to find and process.

# Escape rooms around the world

*Would you be able to beat them all?*

**"The whole group's mood can be lifted, even in those who fail"**

**1 Lockin**
**Manchester, England**

Not only is this an escape mission, but an attempt to find the president's son. In other rooms a sense of urgency is created by handcuffing two team members to a cell. These escape rooms help players live the situation in an environment between real life and virtual reality.

**2 Sherlocked**
**Amsterdam, Netherlands**

Here there are two opposing experiences to choose from. Do you want to escape or break in? In 'The Architect' you have 60 minutes to uncover the world's most powerful secrets, while in 'The Vault' you work your way into a secret safe.

**3 The Escape Game**
**17 US cities**

With a range of themes, this escape room immerses you in realistic settings, from escaping dingy prisons to navigating high-tech spaceships. For the most recent rooms, ready all your senses, as some clues need to be sniffed out.

**4 Palace Games**
**California, US**

Palace Games offers you the chance to go against the original escape artist, Harry Houdini. Designed by the man himself in 1915, The Great Houdini Escape Room lets you take on the ultimate challenge of cracking the legendary artist's own puzzles.

**5 Escapology**
**Worldwide**

The wide range of challenge choices in over 50 locations around the world makes this one of the most rapidly growing franchises. Whether it's the novelty Scooby Doo theme or the high-difficulty submarine escape, their huge range tries to capture the imagination of everyone involved.

© Getty

# The science of escape

*How does the mind cope with code cracking?*

## Conquering common puzzles

Different types of puzzles require a different approach

### Numerical

Numerical clues are not always found in a straightforward equation. Sometimes the hardest part of a numerical puzzle is finding the puzzle itself. One example of these puzzles involves equations using colours, for example (red + green - yellow) x orange'. The only way for this to work is to find these colour clues around the room and figure out what numbers the colours correspond to. Whether they are real items or a decorative picture, search for items and clues that pair up.

### Dexterous

This is a puzzle designed for someone with skilful control, balance, the ability to multitask and plan ahead. Defined by their intricate pathways and confusing networks, maze boards are a common find in escape rooms. Sometimes larger versions require four people to take a corner and remain steady in times of stress. A key is usually found at the centre, and when the team successfully reaches the maze's core they unlock a new aspect of the room.

### Logical

Some of the most frustrating puzzles can test your logic rather than your knowledge. Riddles trip a lot of people up in escape rooms. The two main types are enigma riddles, which are likely to be metaphorical, or conundrums, which test your wordplay ability. Working backwards could help you out, so keep a look out for objects that could fit – or, if you have found a series of letters, what words do they make?

### Visual

Paying attention to every detail is crucial. But once you've seen everything, take time to look again. Observe the surroundings of the room in new ways, because you never know where clues might be hidden. Optical illusions are the perfect way to hide the answers right in front of the players' eyes. Your eyes can sometimes be tricked into not seeing words if they are hidden in the spaces of a picture or blend into a similar background.

### Combinational

Once you have rushed around the room trying to answer all the puzzles, you may be left with multiple answers. Items such as padlocks can be ideal for putting the findings together and progressing to the next stage. Make sure you try all combinations. If it still doesn't open, it may be time to revisit the numerical puzzles once again.

**1 Hard-easy effect**
With the pressure of escape, your mind may work to overcomplicate the puzzles. Your team might miss the obvious answers by looking for something more abstract.

**2 Forward planning**
We often think into the future, planning the next steps ahead. In these rooms events can quickly steer away from what we thought we were working towards. The brain is forced to act quick to modify planned behaviour.

**3 Thinking outside the box**
Getting the job done is easier to do when you know what you're doing. The challenge of escape rooms is accessing new areas of the brain. By encouraging the creative problem-solving aspects of our minds, players are not just finding the answers, but discovering what they are answering.

## 8 Availability heuristic

Time is of the essence in escape rooms. Because you are required to think of solutions quickly, the brain may take a mental shortcut. In a strategy called availability heuristic, your brain chooses information that you can think of quickly. Escape rooms have undertaken much planning to present new challenges, and this potential solution will more often than not be the answer.

## 7 Survival mode

Some escape rooms go to greater lengths to immerse you in the story than others. In the more believable examples, you can begin to convince yourself of the need to escape. When the body is flooded with adrenaline, it can focus the brain and help it perform quicker.

## 6 Selective perception

You've got an inkling of where the clues are taking you and are determined to find other clues that follow the same path. This is called selective perception and might cause you to overlook other vital and unexpected clues.

## 5 Information storage

While clues and answers are dispersed around the room, they are likely to come together in the end. In order to solve the steps, players must keep each finding in the back of their mind. You never know when links between them will need to be made.

## 4 Stressing out

The brain's stress hormone, cortisol, can be released in these high-intensity situations. Affecting performance, this stress is not ideal for problem solving and can lead to impulse actions and poor memory.

# Making the team

What are the best roles to assign to each member in order to succeed?

### Leader

This person is usually the extrovert of the group. Good at guiding the team and keeping the group on track, they oversee the entire team and their general progress.

### Finder

There will nearly always be someone with a keen eye who is best at finding new clues and information. They might not know what they mean, but they will be first to spot hints.

### Worker

To cover all ground, teams need someone who has the patience to cover the painstaking tasks of looking through all the books or sorting all the puzzle pieces.

### Thinker

The natural puzzler of the group puts their brains to good use as the main thinker. Slotting together the pieces found by other members, they focus a lot of their attention on cracking the many codes.

### Leaper

The logic leaper won't follow the average cognitive paths. Coming up with the abstract ideas, they are there to think outside the box. A lot of the time they will be wrong, but when others are stumped their imaginative ideas can pay off.

### Challenger

It may feel like the challenger is against you, but they are essential in reasoning with, and rethinking, ideas. They help to sort the ridiculous from the possible and fine-tune the plan.

© Getty / Illustration by Nicholas Forder

# How to think yourself smart

*How it Works explores the possibility of taking your IQ into your own hands and improving it*

Staring down at the Sunday newspaper crossword, unable to work out nine down, you might be left questioning your intelligence and wondering if there's a way to sharpen your know-how. In recent years digital stores have been flooded with a host of different 'brain-training' apps all promising to help us think ourselves smart, but is that really possible?

Firstly, what exactly is intelligence? Is it something that we solely obtain from school, through our years of life experience, or perhaps a combination of the two? The concept of human intelligence is one that has been debated and researched for more than a century, with no clear answers.

However, what scientists have managed to agree upon is that it can be divided into two categories. The first is known as crystalline or crystallised intelligence. This refers to the intelligence that you might find useful in a pub quiz and centres on an acquired knowledge of the world. The second type, fluid intelligence, is the built-in smarts to problem solve and make decisions. Fluid intelligence is what is measured when taking an intelligence quotient (IQ) test.

So can we think ourselves smart? Cognitive training involves activities and tasks that are designed to help improve our intelligence or stall the inevitable decline of cognitive functions as we age. Brain-training exercises are delivered as repetitive tasks that measure certain cognitive functions, typically assessing what is known as 'working memory'. This is where you can retain information while at the same time completing another task without losing that information. When it comes to brain training, such tasks are a way to improve your working memory, which in turn has been found to improve your fluid intelligence. The idea is that over a set amount of time – for example five 30-minute sessions of training a week for four weeks – repeating these tasks might help you 'think yourself smart'. By gradually improving your test score, much like lifting weights at the gym, these exercises are designed to pump up your brain.

One such breakthrough in these tests appeared in 2008 from neurobiologists Susanne Jaeggi and Martin Buschkuehl, who published a training exercise called the dual n-back task. The basis of the test centres around participants listening to a flow of letters and assessing whether or not the letter matched one previously spoken, while they simultaneously watch a grid of boxes and note when a box appears in the same position as a previous one. Yes, it's just as mentally taxing as it sounds. It was believed that the dual n-back task showed dramatic improvements in peoples' fluid intelligence scores over time, showcasing that what was once thought to be built-in intelligence could potentially be upgraded using these types of tasks. Although Jaeggi and Buschkuehl's dual n-back task was one of the first intensive studies into improving fluid intelligence, 'brain-training' games and apps have been no stranger to the commercial market – one of the most popular being Dr Kawashima's Brain Training for the Nintendo DS released back in 2005. However, there are still debates about the real-world applications of brain training, with some arguing that the improvements are limited to the task itself and not applied to everyday life.

© Getty

# The problem with IQ

Defining intelligence has been a controversial subject within the science community, with many attempting to provide the best possible explanation of how to label the way our brains work. Some even question the legitimacy of the existing standardised testing of intelligence, IQ.

One rather colourful theory was proposed by Harvard professor Dr Howard Gardner back in 1983, whereby he outlined eight different types of intelligence and retains the view that IQ testing is too limited. When applied to the way children are taught in schools, his theory suggests focusing on these intelligence types for effective learning.

**LINGUISTIC INTELLIGENCE**
language and words

**LOGICAL-MATHEMATICAL INTELLIGENCE**
numbers and reasoning

**MUSICAL INTELLIGENCE**
music ability

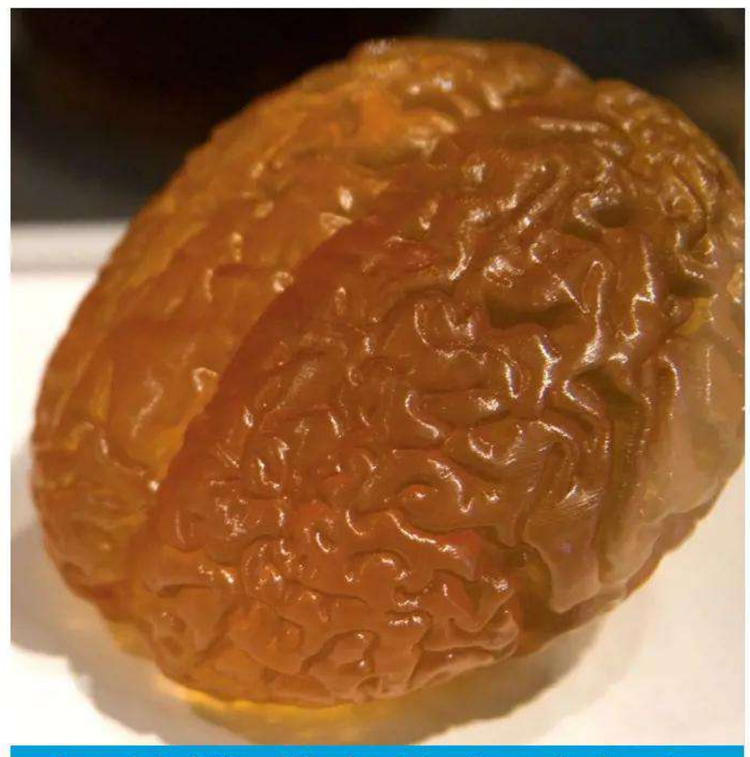
**VISUAL-SPATIAL INTELLIGENCE**
pictures

**INTRAPERSONAL INTELLIGENCE**
self-reflection

**BODILY-KINAESTHETIC INTELLIGENCE**
physical dexterity

**NATURALISTIC INTELLIGENCE**
nature smarts

**INTERPERSONAL INTELLIGENCE**
social skills

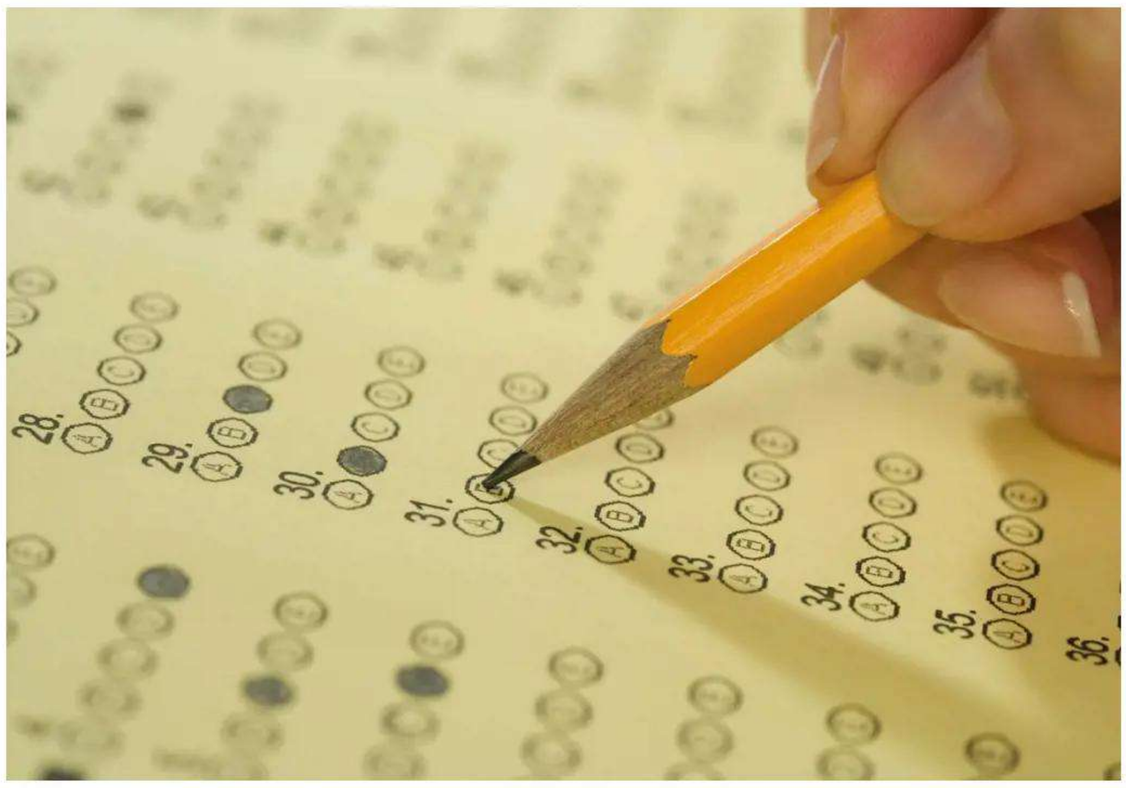


A model of Albert Einstein's brain on display at the 2012 Wellcome Collection's exhibition Brains: The mind as matter

## Is bigger better?

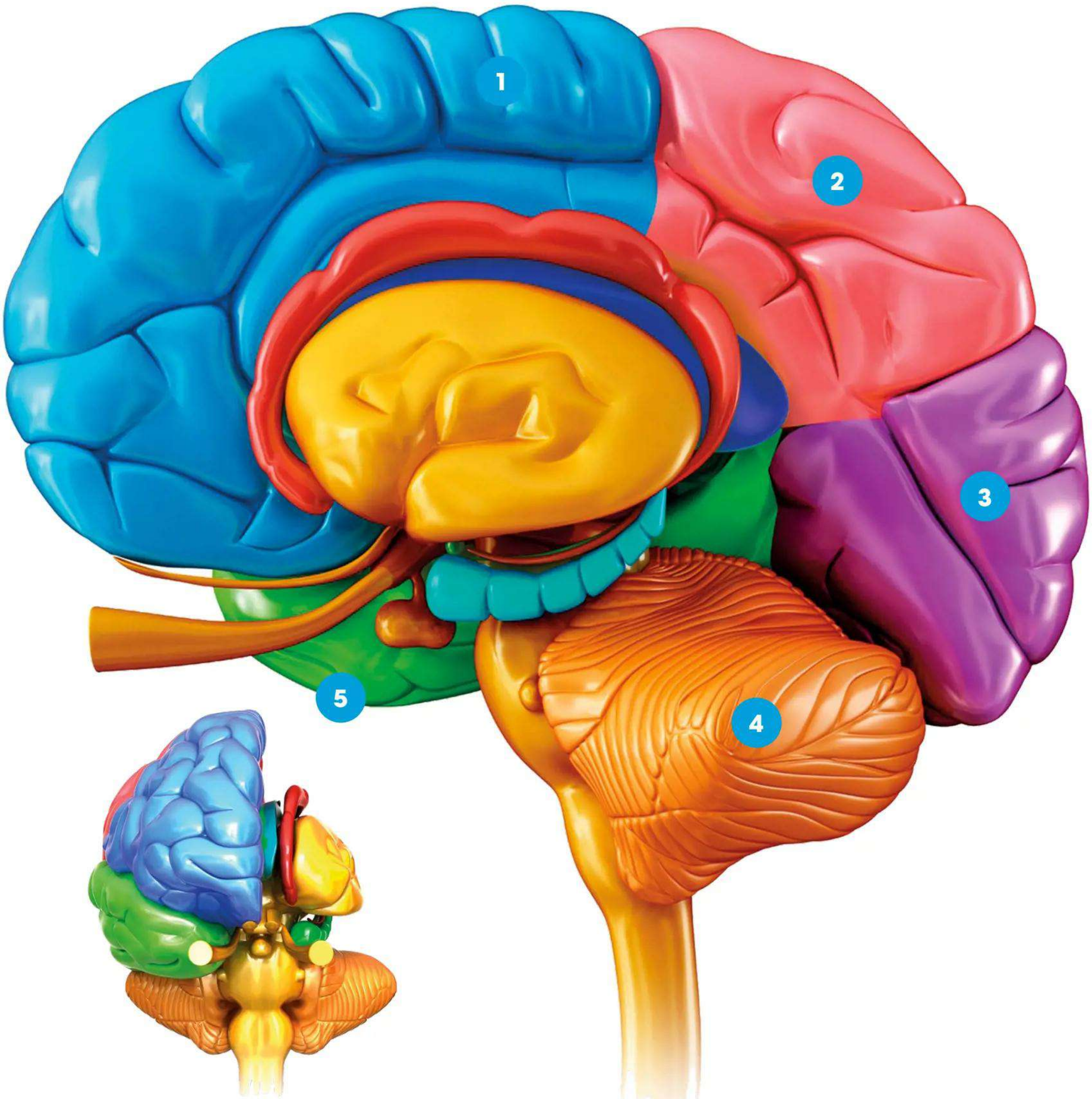
Well, if Albert Einstein's brain is anything to go by, then yes, bigger is better. A postmortem study of the brain of the extraordinary physicist revealed that his parietal lobes were 15 per cent larger than that of the average brain. As only one of the many explanations for Einstein's academic aptitudes, having a bigger brain might affect your intelligence, but some science suggests it's not by much. In a 2018 study led by the University of Pennsylvania, researchers found that out of 13,600 people, those with larger brains did perform slightly better on tests of cognition. Researchers explained that having an additional 100 cubic centimetres of brain tissue would increase the schooling age of a person by less than five months, implying it takes much more than just a big brain to be smart.

**Scientists can use cases where regions of the brain have been damaged to assess their function after monitoring the effects on the patient**



# Inside the brain

*What roles do the different regions of our brains play in our intellect?*




## Intelligence by numbers

**7 years old**
Crows are as intelligent as some children

**500 milliseconds**
It takes around half a second to process sensory information

**135+**
Only one per cent of people have a high IQ score

**50 to 80%**
Genetics accounts for the majority of our cognitive ability

**25**
Your short-term memory peaks in your mid-twenties

**538**
A variety of genes contribute to your intelligence

**1,274 cubic centimetres**
The volume of the average male brain is nearly four times that of a canned drink

**1 Frontal lobe**
The frontal lobe is involved in aspects of our intelligence that include motor function, problem-solving, personality development and language processing. Split into two halves, the left portion of the lobe controls the right side of the body and vice-versa.

**2 Parietal lobe**
Positioned at the top of the brain, the parietal lobe contains the somatosensory cortex, which is responsible for interpreting tactile sensory information such as pain, pressure and touch. Sensory information from almost every part of the body is processed in this part of the brain.

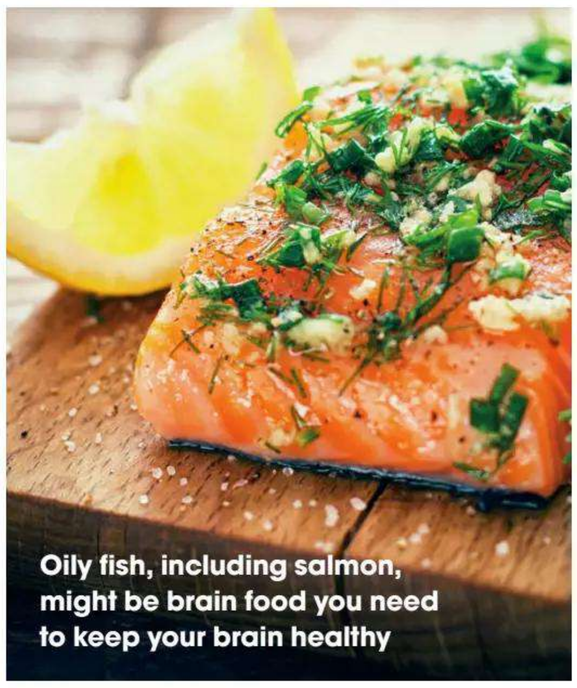
**3 Occipital lobe**
This area of the brain is home to our visual cortex, a region whereby visual information is received, interpreted and processed. Located at the back of the brain, the visual cortex stores this visual information and links any mental images you have to different memories.

**4 Cerebellum**
This tennis-ball-sized region of the brain plays a large part in our motor control, movement and balance. It houses over 50 per cent of the brain's total neurons, which has led scientists to believe it plays a role in higher level cognitive abilities and general intelligence.

**5 Temporal lobe**
Located at the base of the brain, close to the ears, this lobe is home to the primary auditory cortex, which plays a significant role in processing and interpreting language and sounds that we hear. It also contains structures that are involved with the formation of long-term memories.

© Getty

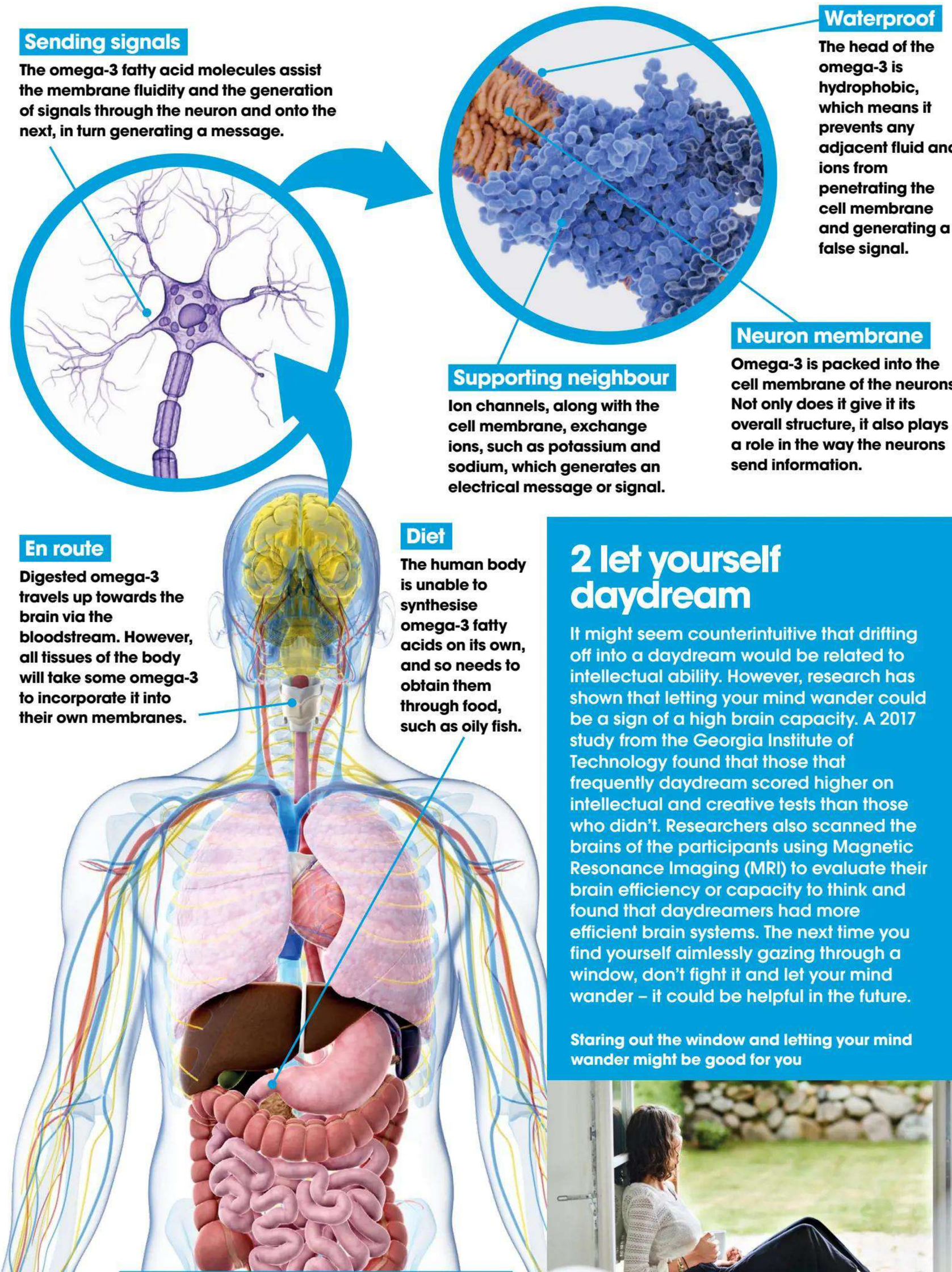
# 10 at-home tips to boost your brain



Oily fish, including salmon, might be brain food you need to keep your brain healthy

## 1 Eat 'brain food'

What we eat can have a massive effect on how well our brains perform. Foods such as blueberries, tomatoes, eggs and broccoli have all been linked to improving our cognitive functions. However, sources of omega-3 fat-rich foods, like salmon or flaxseed, have been at the forefront of brain-boosting foods for some years. Their high essential fatty acid levels are thought to promote healthier brain cells and are used in the construction of cell membranes. Also, low levels of a fatty acid called docosahexaenoic acid, found in oily fish and algae, have been linked to the increased risk of developing Alzheimer's disease. However, what powers our brains on a day-to-day basis is a form of sugar called glucose, which is released into the bloodstream after the stomach breaks down carbohydrate-rich foods.




## 2 let yourself daydream

It might seem counterintuitive that drifting off into a daydream would be related to intellectual ability. However, research has shown that letting your mind wander could be a sign of a high brain capacity. A 2017 study from the Georgia Institute of Technology found that those that frequently daydream scored higher on intellectual and creative tests than those who didn't. Researchers also scanned the brains of the participants using Magnetic Resonance Imaging (MRI) to evaluate their brain efficiency or capacity to think and found that daydreamers had more efficient brain systems. The next time you find yourself aimlessly gazing through a window, don't fight it and let your mind wander – it could be helpful in the future.

Staring out the window and letting your mind wander might be good for you

## 3 Believe you can and you will

Self-belief is a great way to not only boost your confidence but also improve your smarts, a study has shown. When told it was possible to get smarter, it was found that students retained 85 per cent of what they had been taught in class. However, the second group of students were informed it was not possible, resulting in only 54 per cent of them retaining the information. It's thought that belief plays a role in the ease of brain neurons to cooperate.

## 4 Stay social

In a time where face-to-face social interaction is at its lowest, it's important to remain social, not only for fun, but for your brain. Whether it's having a household games night or catching up with friends on a video chat, being social has been shown to improve and help preserve memory functions. Conducted between 1998 and 2004, subjects who were more 'socially integrated' showed higher scores on memory tests conducted every two years.

Taking a moment to reflect might help you make the right decision

## 5 Practise mindfulness

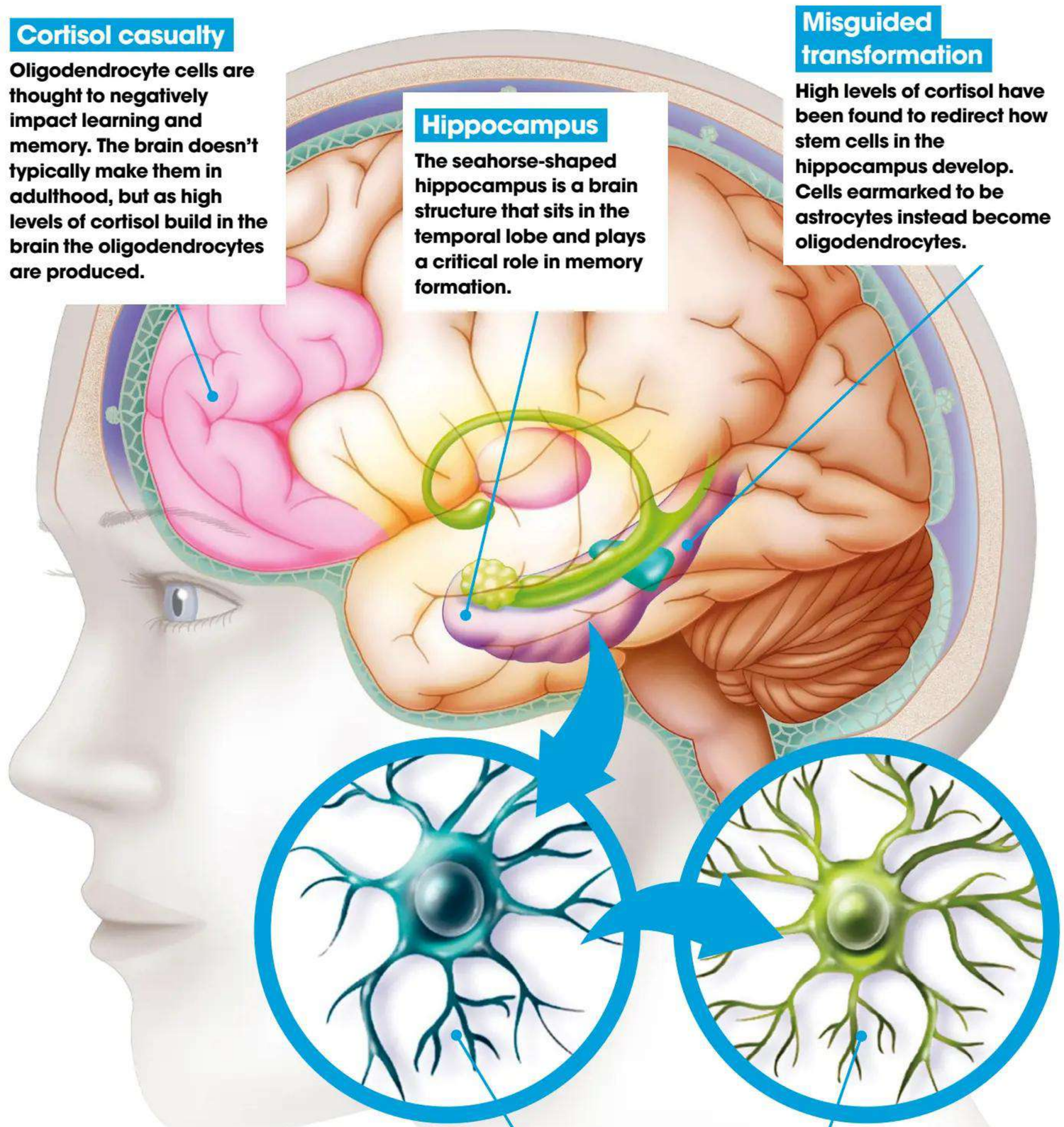
Our ability to make the right decisions is tied to our fluid intelligence and how well we can rationally consider information and make the right choices. Mindfulness, the act of paying attention to the present moment and understanding ourselves, has been found to improve mental health, but also help to better decision-making. Researchers have shown that a brief period of mindfulness, as little as 15 minutes per day, resulted in people making more rational decisions based on available information in the present moment, leading to positive outcomes.

# 6 Stay active

Keeping up with regular exercise can keep your mind sharp as well as helping you stay fit. Studies have found that those that regularly exercise have bigger thinking and memory regions of their brains. Regular exercise has also been found to reduce the body's level of insulin resistance, stress and inflammation, along with promoting the release of chemicals that promote the growth of new blood vessels in the brain. However, one of the most immediate ways exercise can help the brain is by reducing stress. This is achieved by regulating your body's stress hormone, called cortisol. High levels of cortisol in the body have been found to negatively impact the way we think and our memory.

## Change of mind

How cortisol changes the cells inside our brains




**"It's important to remain social, not only for fun, but for your brain"**

© Getty / Shutterstock

## 7 Play some video games

It was commonly believed that playing video games did the opposite of improving the way our brains work. However, plugging in your console and spending the afternoon in a virtual world might have some cognitive benefits. Researchers have found that playing action-oriented video games increases our ability to analyse situations and make quick decisions, along with improving our ability to perceive shapes and colour.

## 8 get lost in fiction

Burying your head in a textbook will help grow your crystalline intelligence and gain knowledge. However, poking your nose into a work of fiction is believed to improve your emotional intelligence. Immersing yourself in books filled with detail, allusion and metaphors activates the same regions of the brain that would be simulated in real-life situations. Reading moral dilemmas in fiction, for example, is known to exercise the brain and increase our capacity for empathy.

## 9 Learn to play an instrument

It might be time to dust off that guitar that's tucked away in the attic or pick up that recorder for the first time since school to help improve your cognitive function. Other than acquiring a new skill, learning to play an instrument has been found to engage almost all parts of the brain and improves language and cognitive skills.

## 10 Drink green tea

How much difference can a cup of green tea make to the brain? Well, a long-term study published in the science journal Experimental Gerontology has found that a chemical compound found in green tea called catechin might be able to reduce cerebral atrophy – loss of brain cells – and function. The study used mouse subjects over 12 months and discovered that green tea catechin effectively suppressed atrophy, along with improving brain function in the brains of older mice subjects.

## The 'smart drug' myth

Whether you're cramming for a university exam or working late on tomorrow's big presentation, popping a 'smart pill' might sound like the perfect solution to get you through. Back in 2014 a drug called modafinil hit the newsstands, being branded as a 'smart drug' to improve brain performance. Typically used to treat patients with narcolepsy, the pill promotes 'wakefulness' in those that take it. However, when it comes to boosting our brain power, studies have shown that modafinil did not improve cognitive function, but instead slowed study participants' responses when compared to those given a placebo pill.

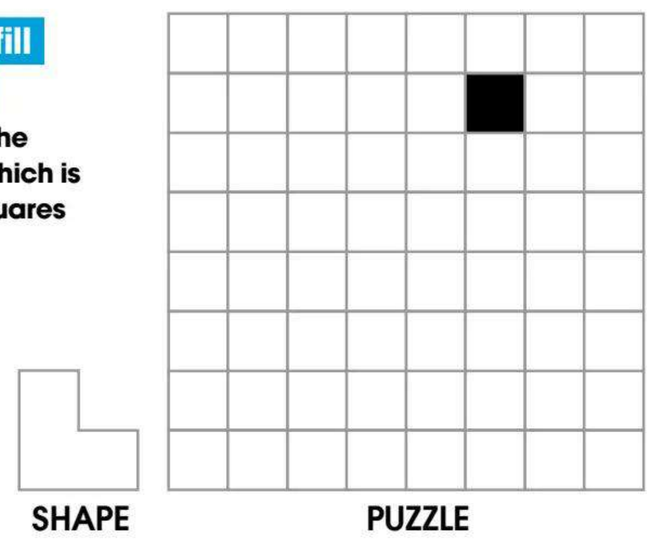
# Test your smarts

*Can you complete them all?*

An aspect of our intelligence and cognitive function is our willingness to persist with a task despite initially finding it difficult. This is what is known as cognitive engagement, and is defined as the effort that students are willing to invest in working on a task.

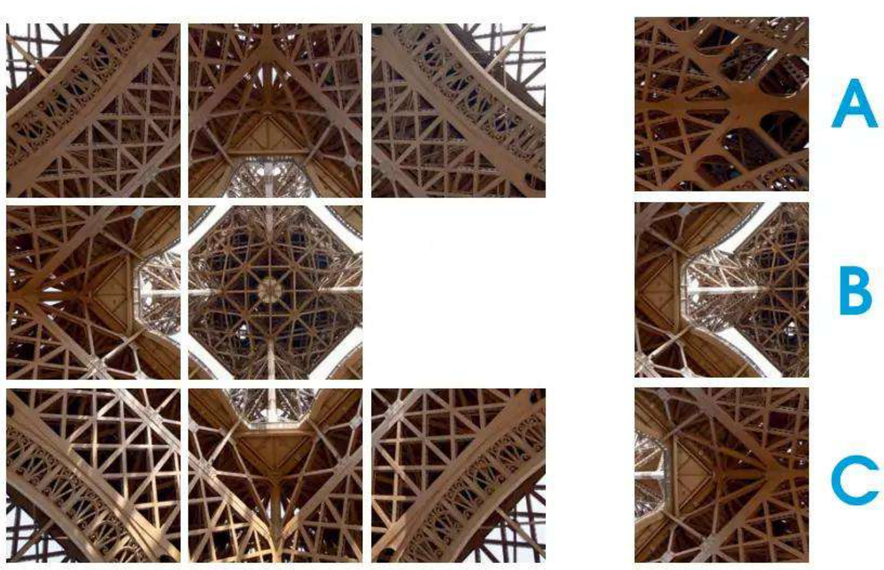
## Q1 Can you fill the jigsaw?

**Draw enough of the jigsaw shape – which is equal to three squares – onto the grid to completely fill it.**




## Q2 Complete the image

**Can you spot the correct square to complete the final image?**




## Q3 What number comes next in the sequence?

**3, 6, 18, 72 .....** **4, 10, 28, 82, 244 .....**

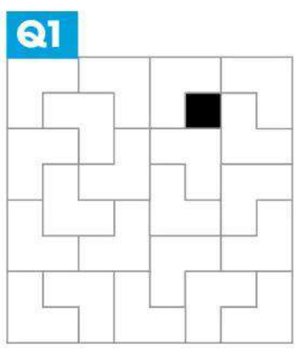
**20, 19, 17, 14, 10 .....** **9, 11, 20, 31, 51 .....**

## Q4 Can you match the synonyms?

| | | |
|---|---|---|
| A DETRIMENTAL | E ABUNDANT | I HARMFUL |
| B CONNECT | F LOQUACIOUS | J PLENTIFUL |
| C DISPERSE | G TALKATIVE | K JOIN |
| D OFTEN | H SCATTER | L FREQUENT |

## Answers

**Q1**



**Q2: C**

**Q3**

**360** (X2, X3, X4, X5) **5** (-1, -2, -3, -4, -5)

**730** (+6, +18, +54, +162, +486) (X3)

**82** (EACH NUMBER IS THE SUM OF THE PRECEDING 2 NUMBERS, 9+11=20)

**Q4** A & I, C & H, E & J, F & G, B & K, D & L

# Q&A: Brain-training explained

*Dr Claudia von Bastian, a lecturer in psychology at the University of Sheffield, explains some of the evidence behind brain training and how it might not be for everyone*

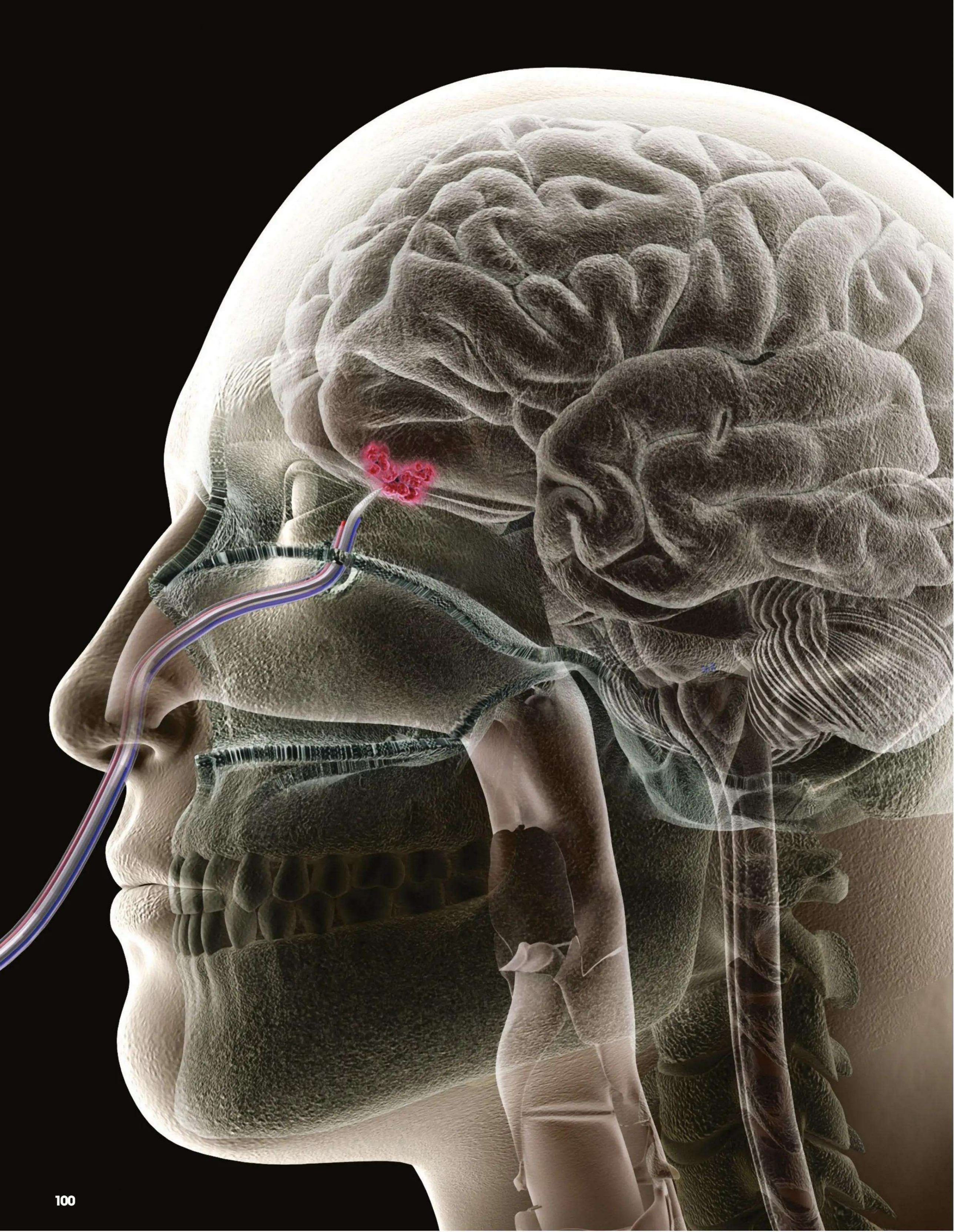
**Does intelligence change with age?**
The developmental evidence and life span studies show that fluid intelligence and crystalline intelligence both grow and increase and become better. Crystalline intelligence more or less grows all life long, whereas in fluid intelligence it grows and grows and grows up to around the 20s, and then it starts to flatten. Then it goes down in older age and you have a decreased fluid intelligence compared to earlier in life. You can think of it as like an inverted 'U' curve shape, but not an extreme 'U'. It's growing steeper in early life until the frontal lobes are fully developed in the early 20s, and then it flattens, and then it gradually decreases. In crystalline intelligence, it rises and rises and then maybe in midlife it reaches a plateau, but then it very slightly increases further or at least stabilises, but it doesn't decrease.

**Can brain training help flatten that curve as we age?**
That would be the idea behind brain training, that you would be able to counteract that decline, especially in ageing. However, the evidence for that is very, very weak. It depends a little bit on what your goal is. If you want to really flatten the curve so that you don't have that decline in a meaningful way, that is what we don't have any evidence for. What you can do is just practise the tasks that are assessed extensively, and then you will show better test scores, but it doesn't mean anything if you don't seek to generalise it to other contexts. I would say at the moment the evidence isn't there that this really works.

**Is there a particular age where brain training would be most effective?**
I know of no convincing evidence, but I would say so. Intuitively you would think that it would help most when you are in development or already on the decline, so you would think it helps most for older adults, or if you're still developing, so it might help most for young children, but there is no convincing evidence that actually confirms that, even though it would be plausible.

**Are brain-training tasks a 'one-size-fits-all' solution?**
That would be ideal, right? But that's exactly the problem when people try to find this one-size-fits-all kind of approach, this kind of quick-fix solution that could make people miraculously smarter, but that doesn't seem to work. For example, brain training that tries to make your kids smarter by practising working memory. It might be better to actually practise maths if you want to improve your maths skills. Or if you want to improve some certain aspects of your daily life, it might be better to actually practise those aspects rather than trying to do this brain training as a quick-fix solution. I think, if anything, you would need more tailored interventions than broader interventions.

© Getty



# Medicine

# Brain surgery

*Discover one of the most challenging of all medical specialties. If you thought rocket scientists had to pay attention to detail, wait until you meet this lot...*

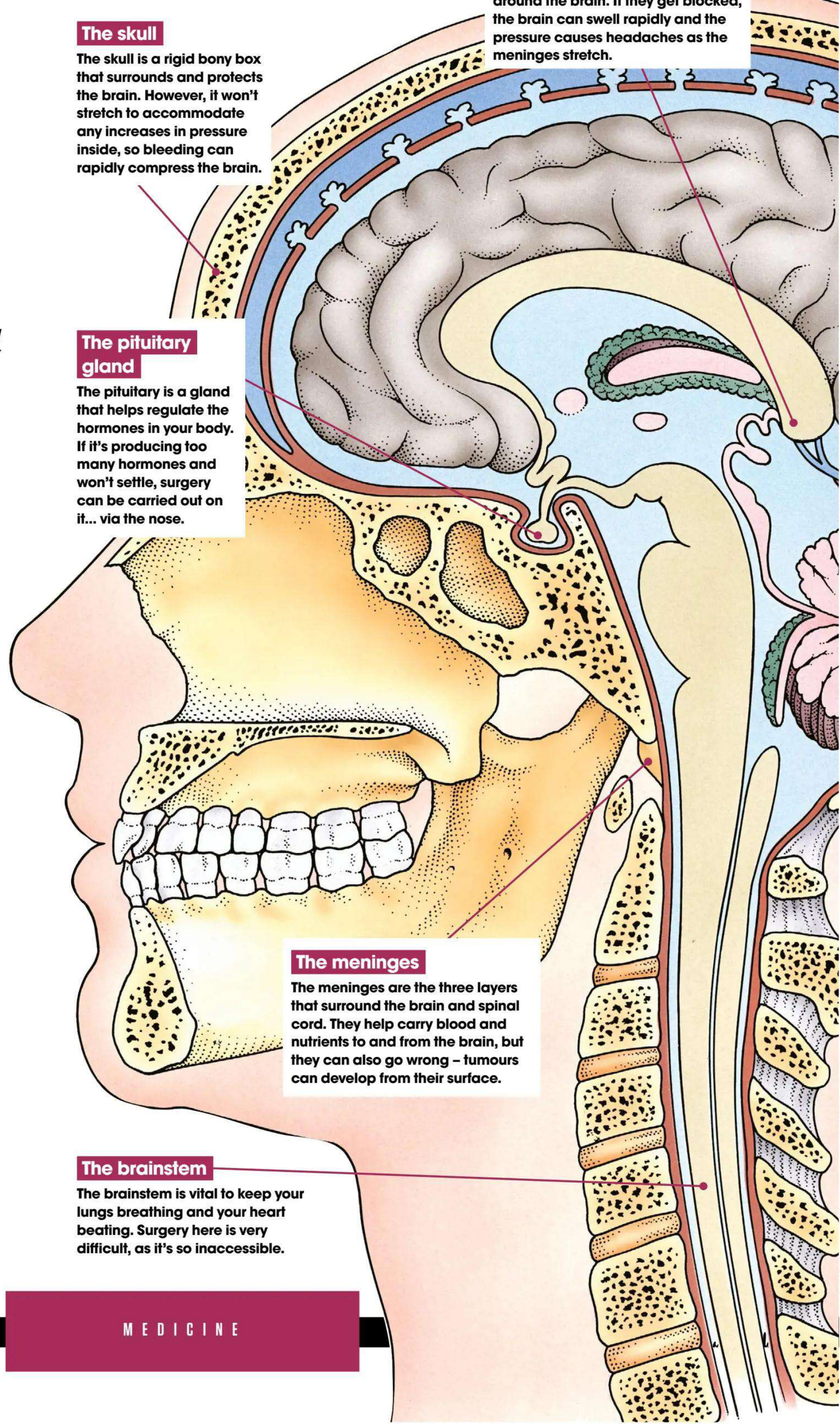
There is still so much we don't know about the human brain. However, if something goes wrong and it needs an operation, you will find yourself in need of a neurosurgeon. These guys can operate on the vast number of structures within the brain and spinal cord, and have a full arsenal of techniques and – literally – cutting-edge technologies to hand.

A neurosurgeon's workload comes in two main forms. The emergency work is often a result of road traffic accidents or fights, and often affects young men with head injuries. These patients may have bleeding within the skull, which is exerting pressure on the brain – the neurosurgeon must relieve that pressure. There is also the planned work, where neurosurgeons try to remove tumours with meticulous detail to surrounding structures.

The technology starts a long way before the operation. Advanced CT and MRI scans allow for 3D reconstructions and images that we couldn't have even dreamed of a few years ago. This allows neurosurgeons to plan the precise timing and nature of surgery – where to cut and how deep to make the incision. The imaging falls within a team approach to caring for these patients, as the team is every bit as important as the technology.

Surgery is becoming less invasive as time goes on. The advantages of this are smaller incisions, less disruption to surrounding tissues, less pain and shorter hospital stays. Surgeons now often use powerful microscopes with bright lights to

## Let's look inside the skull...

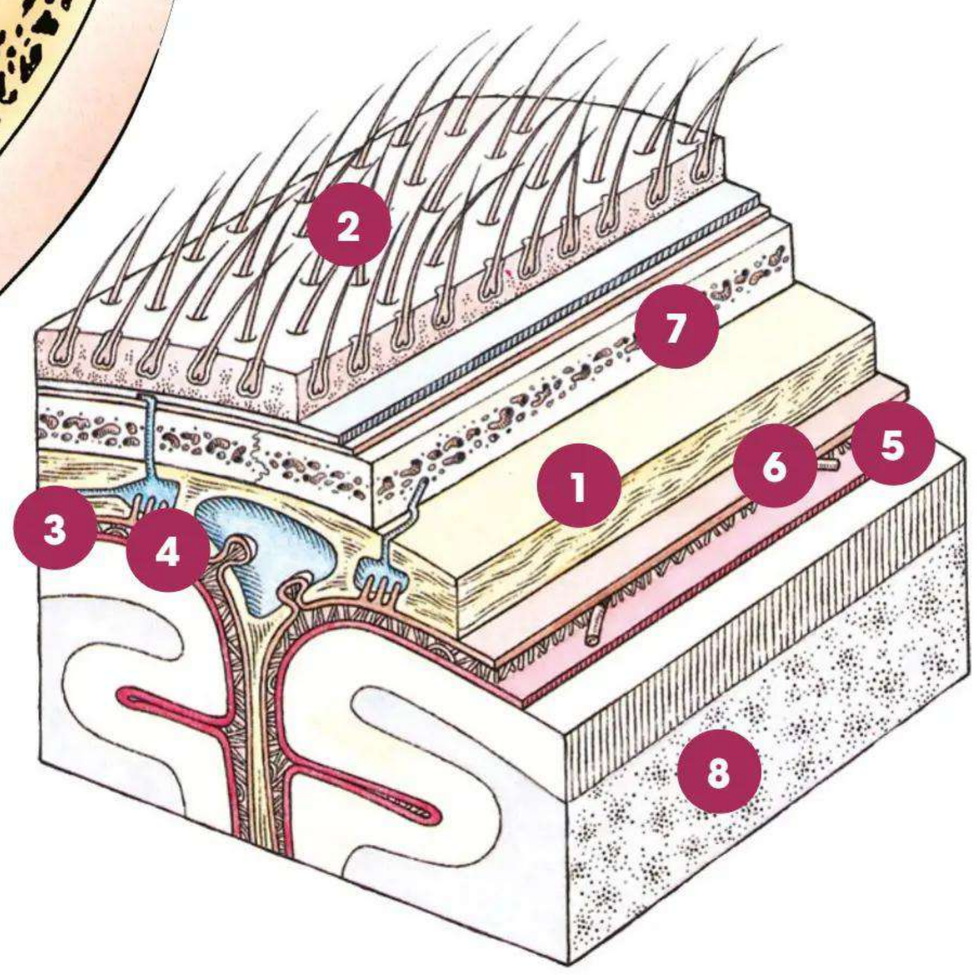


### The grey matter

The grey matter contains complex areas of memory, personality and function. Surgery here can have few effects, or it can have devastating effects, such as taking away your memories or changing your personality.

### The cerebellum

The cerebellum controls your fine movements. Surgery here can leave you with balance problems.




## Layers surrounding the brain

1 Arachnoid mater
2 Skin
3 Dura mater
4 Blood vessels in the subarachnoid space
5 Connective tissue
6 Pia mater
7 Cranium – bone of the skull
8 White and grey matter of the brain

# Why do you need brain surgery?

*Some of the common reasons for performing brain surgery*

### Trauma

Often following road traffic accidents or fights, head injuries are common – especially in young men. They can range from minor to life- threatening. Sometimes surgery won't help, but if the bleeding can be stopped in time, you need a neurosurgeon.
**Appropriate procedure:** Craniotomy
**Procedure length:** 1-4 hours
**Recovery time:** Weeks to months
**Effectiveness of procedure:** If early enough, completely effective. If late, it can be devastating.

Severity of condition: ●●●●● Difficulty of surgery: ●●●○○

### Tumours

Brain tumours present themselves in a variety of ways – some people have headaches, some have co-ordination problems, and some have no symptoms at all. Metastatic tumours, where growth is from another source (such as breast or bowel), are the most common type.
**Appropriate procedure:** Craniotomy or stereotatic surgery
**Procedure length:** 2-12 hours
**Recovery time:** Weeks
**Effectiveness of procedure:** Ranges from no effects to severe effects.

Severity of condition: ●●●●● Difficulty of surgery: ●●●●○

### Cerebral aneurysms

Swellings in the fine blood vessels within the brain can burst, leading to life-devastating bleeding. Preventing the bleeding is the trick here.
**Appropriate procedure:** Endovascular coiling
**Procedure length:** 1-3 hours
**Recovery time:** Days
**Effectiveness of procedure:** If coiled before a major bleed, it's likely to provide an excellent outcome.

Severity of condition: ●●●●○ Difficulty of surgery: ●●○○○

### Epilepsy

Surgery for epilepsy isn't for everyone. In some cases, where medicines can't control the fits, surgery may be appropriate if the fits are arising from one area.
**Appropriate procedure:** Temporal lobectomy
**Procedure length:** 2-4 hours
**Recovery time:** Days
**Effectiveness of procedure:** 95% chance of success in selected patients.

Severity of condition: ●●○○○ Difficulty of surgery: ●●●○○

### Parkinson's disease

Some patients with Parkinson's disease will benefit from some extra stimulation of their nerves. Implanting a special nerve 'pacemaker' isn't easy, but this deep brain stimulation can produce stronger signals.
**Appropriate procedure:** Deep brain stimulation
**Procedure length:** 2-4 hours
**Recovery time:** Days
**Effectiveness of procedure:** Medium to good.

Severity of condition: ●●●○○ Difficulty of surgery: ●●●●○

© DK Images / US Navy

## The right tools for the job...

Discover the equipment used by brain surgeons

### Guglielmi detachable coil

These platinum wires are fed into small aneurysms (enlarged arteries) within the brain via an artery in the groin. Once coiled up inside the aneurysm sac, they stop blood flow and thus prevent bleeding.

### Surgical microclamps

These small clamps can be used to grab tumours to help the surgeon dissect them away from surrounding structures.

### High- performance microscope

These powerful microscopes with bright lights enable surgeons to operate through tiny incisions or keyholes, which prevents damage to those important surrounding structures.

help them remain as precise as possible. These microscopic techniques require a huge amount of skill, dexterity and hand-eye co-ordination that would impress even a fighter pilot.

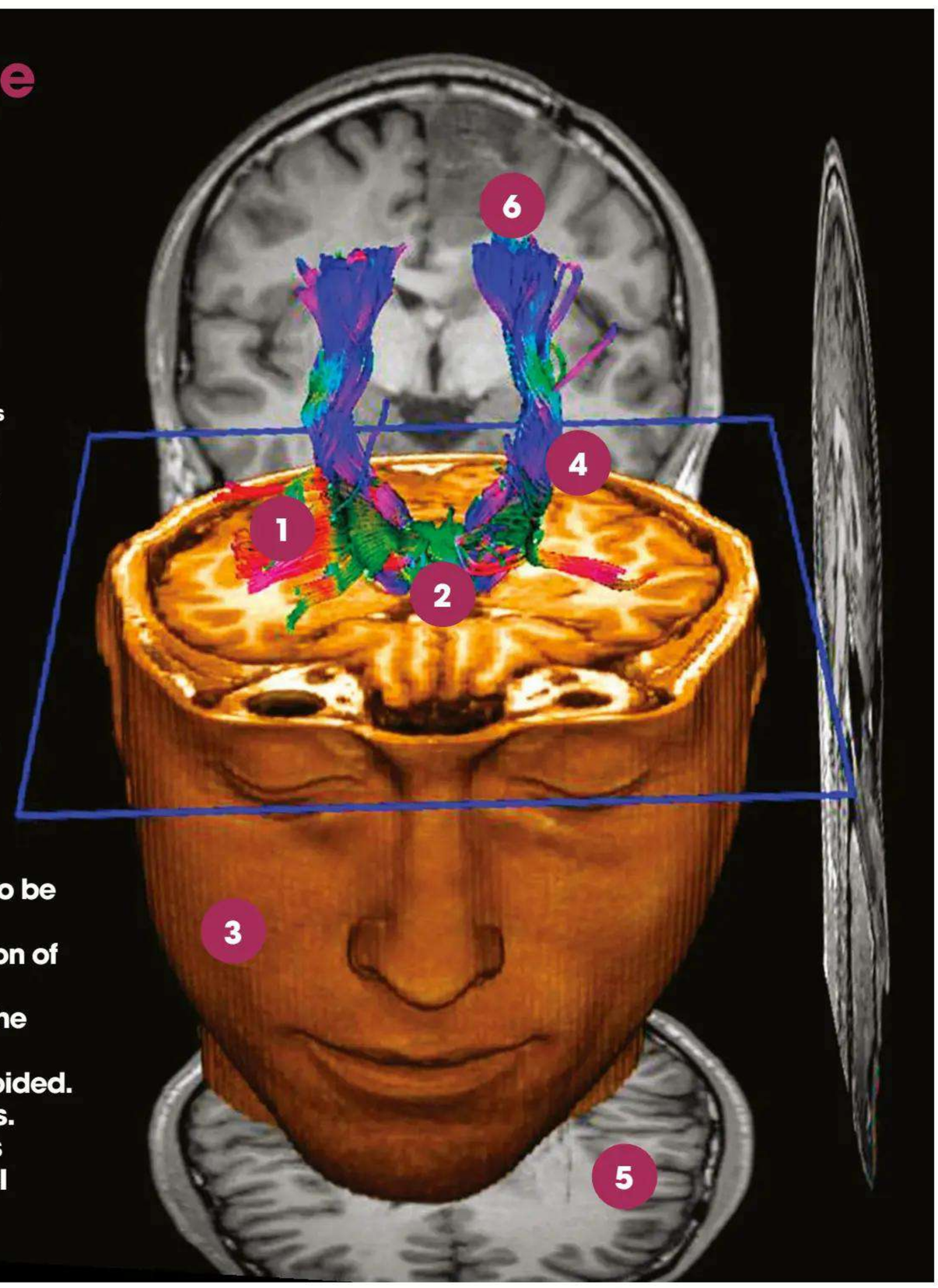
New neuro-navigation techniques and robotic surgery can help surgeons get to the hard-to-access places, which previously would have been inaccessible. Special scanning cameras and computers are used during the operation and are matched to a pre-existing scan to guide the surgeon's hand – much like the satellite navigation systems used by drivers. Neuro-endoscopy, which involves the use of tiny cameras to access the brain, is opening up many new opportunities in brain surgery. Incredibly, it's possible to access the brain via a tiny cut in the back of the nose, too.

The brain is the network hub of the human body, co-ordinating all of the sensations we feel and then providing instructions for the complex movements we perform. Although it receives all of the pain signals from the body, the brain itself doesn't have pain receptors. This means that there is potential for neurosurgery to be carried out with the patient awake. However, there are pain receptors in the skin, muscles and linings that surround the brain, so it certainly isn't for everyone and it isn't performed everywhere.

Incredibly, there are bits of your brain that you can survive without – and you might not even notice any difference. It really depends on which part of the brain is removed – remove even a small part of the brain stem, for example, and you'll die instantly. Removing or cutting larger parts of the main brain can leave just a few effects, such as memory problems. However, these discoveries were often made at the peril of surgeons operating and experimenting on patients in years gone by, which are now lessons confined to the history books.

## Cutting-edge technology

**Removing brain tumours is all in the planning. Actually taking them out is easy – leaving in what's important is what's hard. Knowing precisely where to cut is the difference between a good and a bad functional outcome for the patient. Especially in young people, having good physical skills and memories is just as important as staying alive. CT scans use multiple x-rays to build up pictures and are good at looking for bleeding. MRI scans use magnets and change the directions of the atoms within cells; these are best at looking for tumours. The latest technology fuses MRI with high-powered computers to build up 3D models of individual nerve fibres, based upon the direction of movement of water within these fibres – diffusion MRI.**




1. This brain tumour needs to be removed.
2. A roadmap of the direction of nerve fibres is created.
3. 3D reconstruction helps the surgeon plan a route.
4. Healthy fibres can be avoided.
5. Conventional MRI images.
6. The movement of water is picked up by modern MRI diffusion techniques.

# Transnasal brain surgery

A breakthrough technique that increases operability

**Access**

Surgeons gain access by going through the back of the nose and the sinuses.

**Moving forwards**

These minimally invasive techniques allow surgeons to access areas which were previously considered inoperable.

**Where?**

This technique can be used to get tumours around the base of the skull and the top of the spine.

**Scarless**

Small tumours and those up to the size of tennis balls can be treated this way – but the patient still remains scarless!

**The right kit for the job**

A super-specialised tiny camera and light is inserted via the back of the nose to get access.

# Time critical!

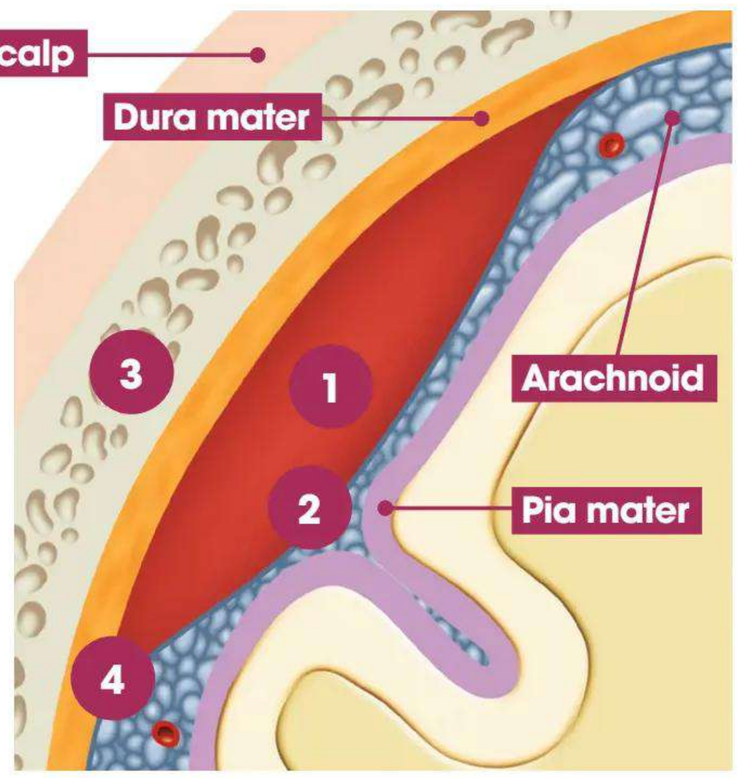
A haemorrhage needs urgent attention to save a life

**1 Clot**
A blood vessel has broken, forming a clot (haematoma).

**2 Under pressure**
The clot is causing increased pressure within the skull, squeezing the brain.

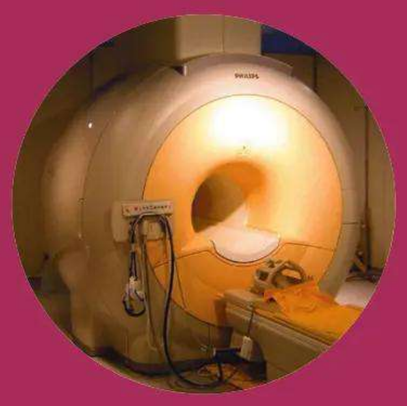
**3 Skull**
Since the skull is rigid, the brain is forced downwards towards the only exit – into the spinal column. This rapidly leads to death unless treated, as it damages the vital brainstem.

**4 Life-saving**
In true life-saving surgery, a surgeon will cut away a small piece of skull (craniotomy), clear away the clot and stop the bleeding.




# The right tools for the job...

More equipment used by brain surgeons



**Navigation systems**

This computer system merges pre-operative CT and MRI scans with intra-operative information gathered from lasers and infrared. The result is a 'map', which surgeons use to navigate to difficult-to-find tumours.

**Burr-hole drill**

Although not used much any more in the Western world, a drill is used to evacuate blood clots which form around the brain following accidents. They are still used in some parts of the world.

**Haemostat**

A vital surgical tool, a haemostat is a scissor-shaped device used to control bleeding. They are locked in place via a series of interlocking teeth, which can be varied according to the amount of pressure needed.

© Science Photo Library / Marvin 101 2009 / DK Images

# Is it possible to see our thoughts?

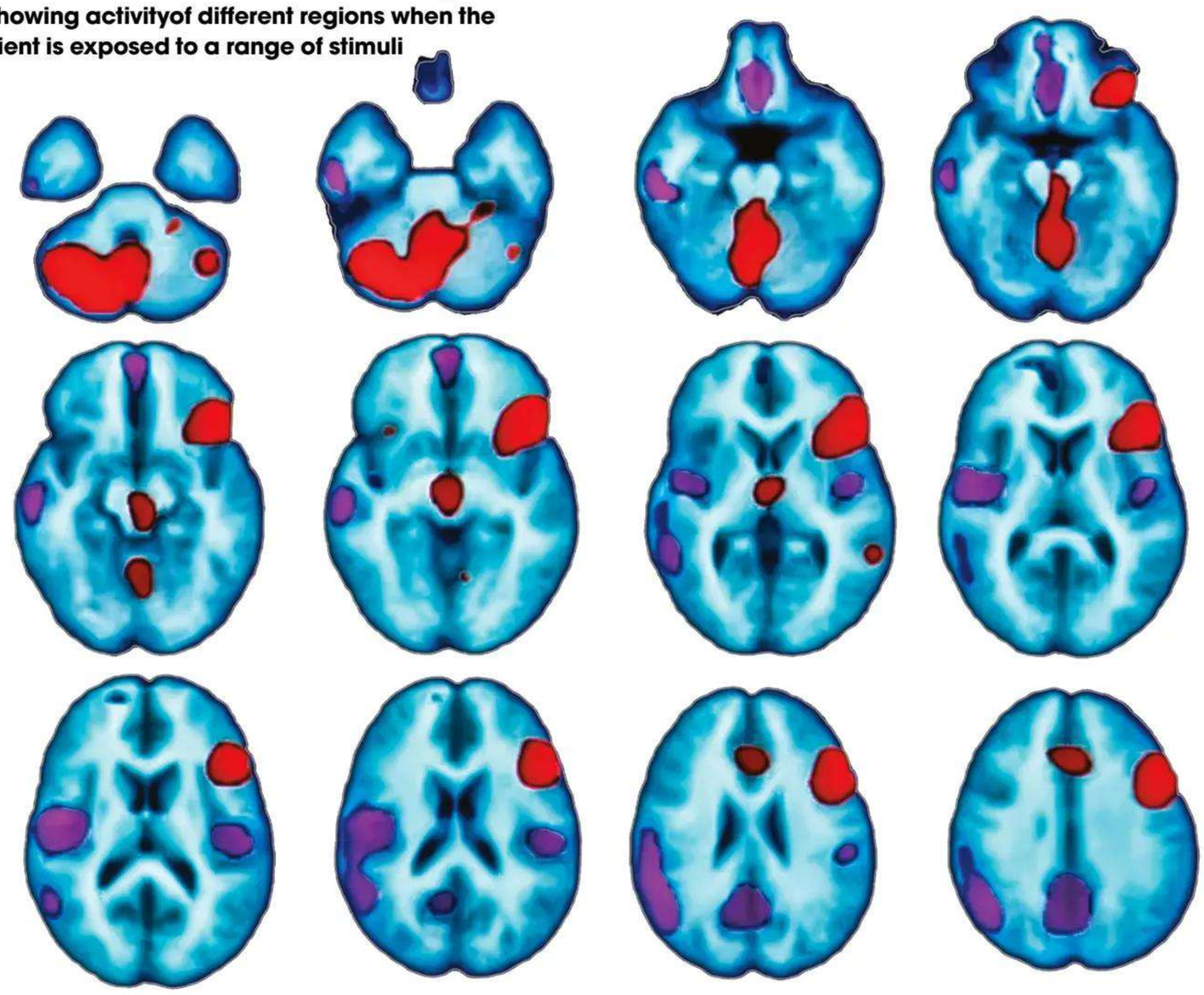
*The brain is perhaps the most vital ofthe body's vital organs, yet in many ways it's also the least understood*

At its most simple level, the brain is a series of interconnecting neurons that relay electrical signals between one another. They are 'all or none' transmitters as, like a computer, they either transmit a signal (like a binary '1') or do not ('0'). Different neurons are receptive to different stimuli, such as light, touch and pain. The complex activity of these neurons is then interpreted by various parts of the brain into useful information. For example, light images from the eye are relayed via the optic nerve to the occipital cortex located in the back of the skull, for interpretation of the scene in front of you.

The generation and interpretation of thoughts is a more complex and less well understood process. In fact, it is a science of its own, where there are many definitions of what a 'thought' is, and of what defines consciousness. In an effort to better define these, doctors, scientists and psychologists have turned to novel imaging techniques to better understand the function of our minds. Research into understanding brain activity and function has led to some of the most advanced imaging techniques available. This has helped to treat conditions such as Alzheimer's dementia, epilepsy and stroke, as well as mental illnesses where there is not necessarily a physical problem within the brain. It has also led to benefits for imaging other diseases in other parts of the body, including several forms of cancer.

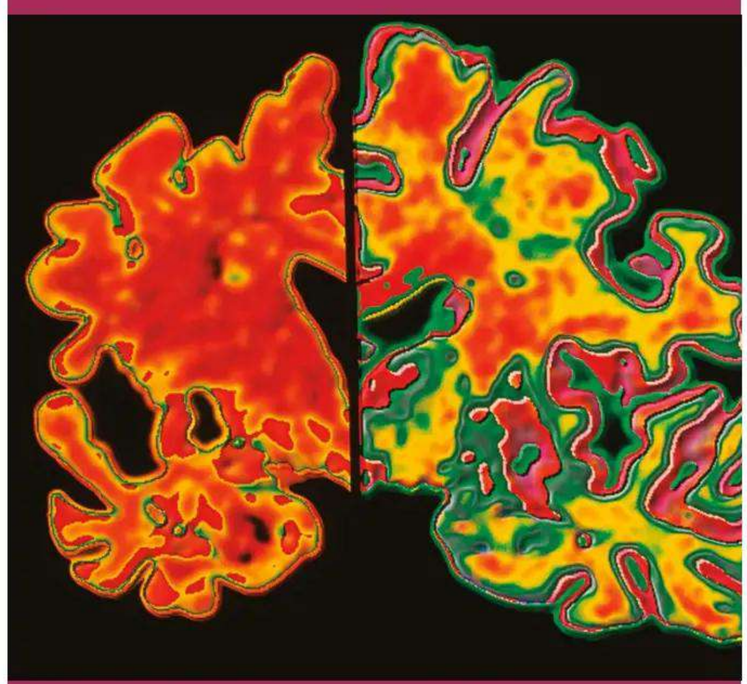
These advanced imaging techniques include scans to produce images of the anatomical structure of the brain, and interpretation of energy patterns to determine activity or abnormalities. Scientists have started to ascertain which parts of the brain function as we form different thoughts and experience different emotions. This means we are very much on the brink of seeing our own thoughts.

**This CT scan of the brain has fusedPET images over it, showing activityof different regions when the patient is exposed to a range of stimuli**



## Imaging Alzheimer's

Alzheimer's disease is a potentially debilitating condition, which can lead to severe dementia. The ability to diagnose it accurately and early on has driven the need for modern imaging techniques. The above image shows a PET scan. The right-hand side of the image (as you look at it) shows a normal brain, with a good volume and activity range. On the left-hand side is a patient affected by Alzheimer's. The brain is shrunken with fewer folds, and a lower range of activity – biologically speaking, there are far fewer neurons firing.



# Picking apart the brain

**1 The frontal lobes**
These lobes on the folded cerebral cortex take care of thought, reasoning, decisions and memories. It's believed to be largely responsible for our personalities.

**2 The sensory and motor cortexes**
The pre- and post-central gyri receive the sensory information from the body and then dispatch orders to the muscles, in the form of signals through motor neurons.

**3 The occipital cortex**
In the posterior fossa of the skull, this cortex receives impulses from the optic nerves to form images. These images are infact seen upside down, but this area enables them to be interpreted the right way up.

**4 The cerebellum**
This is responsible for fine movements and co-ordination. Without it, we couldn't write, play musical instruments or perform any task that requires precise actions.

**5 The pituitary gland**
This tiny gland is responsiblefor hormone production throughout the body, which can thus indirectly affect our emotions and behaviours.

**6 The brainstem**
Formed from the midbrain, pons and medulla oblongata, the brainstem maintains the vital functions without us having to think about them. These include respiration and heart function; any damage to it leads to rapid death.

## How can we view the brain?

### Computed tomography (CT)

**This combines multiple X-rays to see the bones of the skull and soft tissue of the brain. It's the most common scan used after trauma, to detect injuries to blood vessels and swelling. However, it can only give a snapshot of the structure so can't capture our thoughts.**

### Magnetic resonance imaging (MRI)

**MRI uses strong magnetic fields to align the protons in water molecules in various body parts. When used in the brain, it allows intricate anatomical detail to be visualised. It has formed the basis of novel techniques to visualise thought processes.**

### Functional MRI (fMRI)

**This form of MRI uses blood-oxygen-level-dependent (BOLD) contrast, followed by a strong magnetic field, to detect the tiny changes in oxygen-rich and oxygen-poor blood. By showing pictures to invoke certain emotions, fMRI can reveal which areas of the brain are active during particular thoughts.**

### Diffusion tensor imaging (DTI)

**This MRI variant relies on the direction of water diffusion within tissue. When a magnetic gradient is applied, the water aligns and, when the field is removed, the water diffuses according to a tissue's internal structure. This allows a 3D image of activity to be built up.**

### Positron emission tomography (PET)

**This bleeding-edge technology detects gamma rays emitted from biologically active tissues based on glucose. It can pick up unusual biological activity, such as that from cancer. There have been recent advances to combine PET with CT or MRI to obtain lots of important data quickly.**

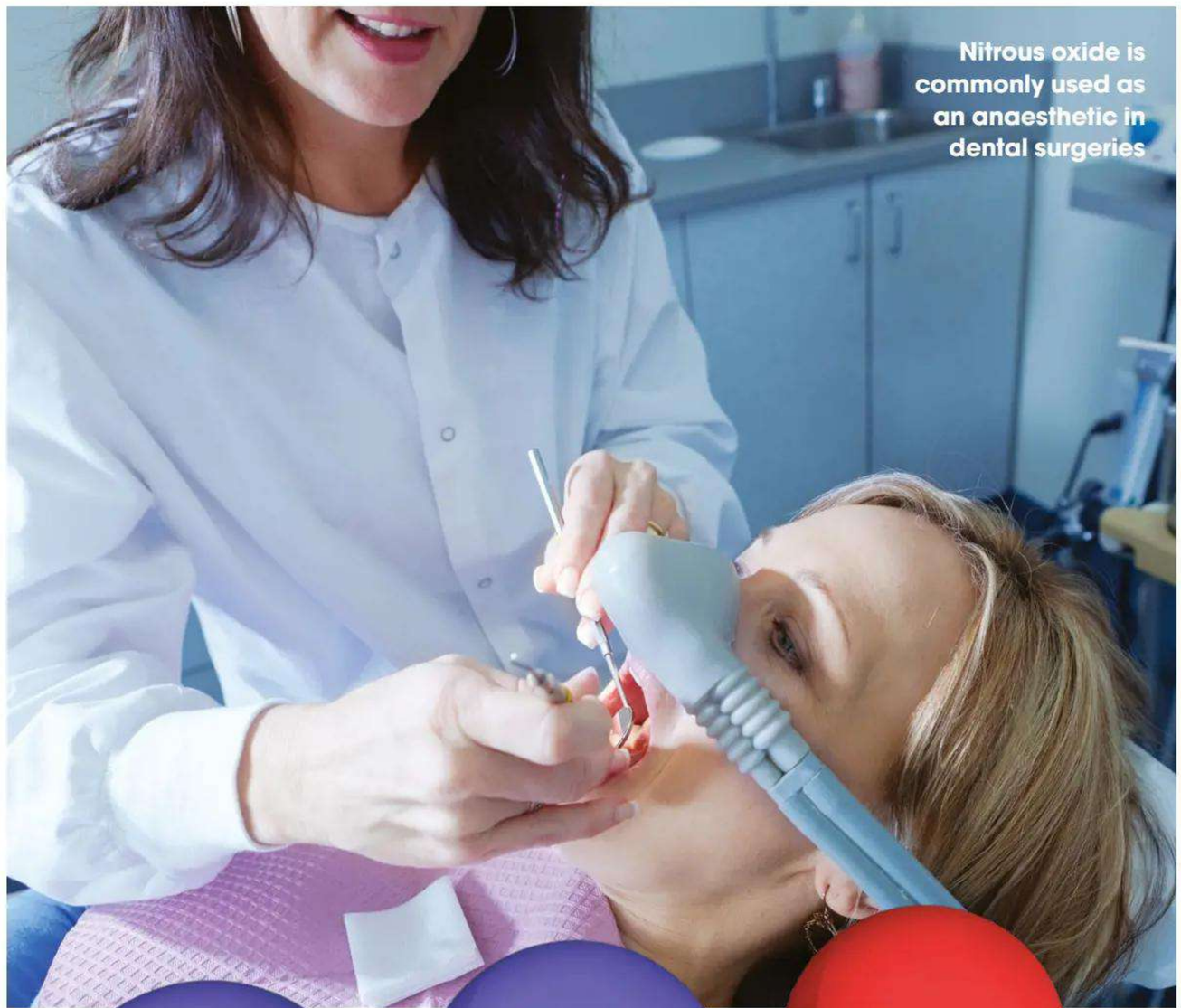
© Science Photo Library / Alamy

# What is nitrous oxide?

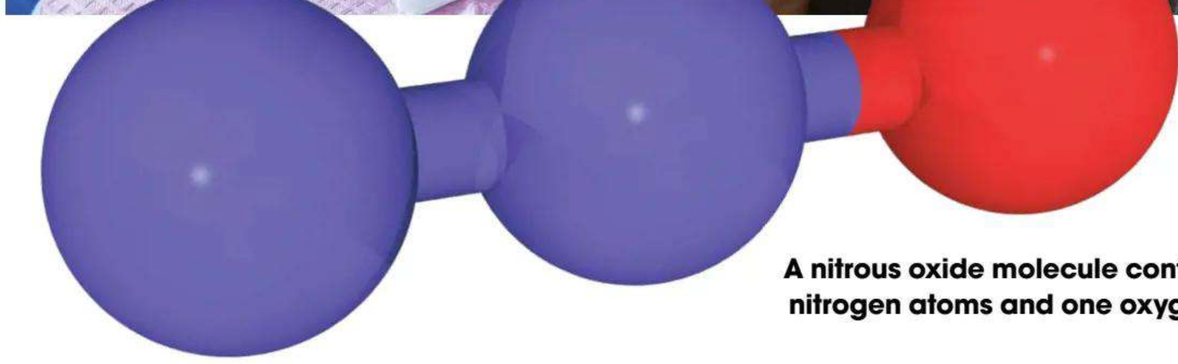
*Discover the science of laughing gas*

Nitrous oxide (N2O), also known as laughing gas and NOS, is a colourless gas at room temperature. The sedative and anti-anxiety side effects of this gas make it a useful tool for dentists and other medical professionals who carry out minor surgeries. A patient who is offered this gas will need to wear a mask over their nose and mouth throughout the entire procedure and will remain awake. While medical professionals know how to administer safe amounts of this gas, inhaling nitrous oxide can result in hallucinations and a feeling of dissociation with the body. Too much of the gas can cause people to become dizzy, pass out and even die. In low volumes and controlled concentrations, however, nitrous oxide is used as a painkiller and can cause people to laugh with euphoria – giving it the nickname 'laughing gas'.

Naturally present in Earth's atmosphere, nitrous oxide is one of the ten primary greenhouse gases and is 300 times more harmful than carbon dioxide in terms of its contribution to global warming. Most of the gas in the atmosphere is released as a product of agriculture and will remain there for around 114 years before finally breaking down. The widespread use of certain fertilisers in modern farming has increased the volume of nitrous oxide in the atmosphere. These ammonium-based fertilisers improve the growth of crops, but the plants don't absorb all the fertiliser that's being sprayed onto them. As the fertiliser runs into the surrounding fields and streams, microbes in the soil convert the ammonia into nitrite, then nitrate and finally nitrous oxide gas.



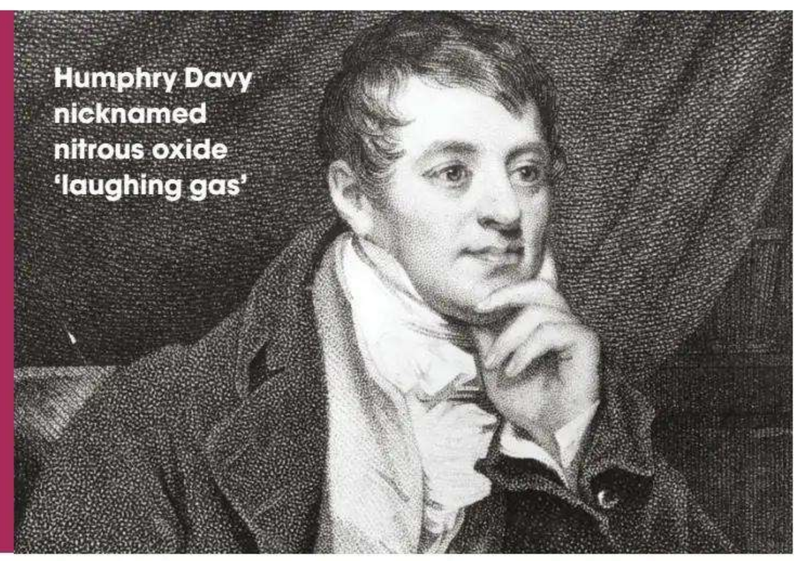
Nitrous oxide is commonly used as an anaesthetic in dental surgeries



A nitrous oxide molecule contains two nitrogen atoms and one oxygen atom

## Laughing gas

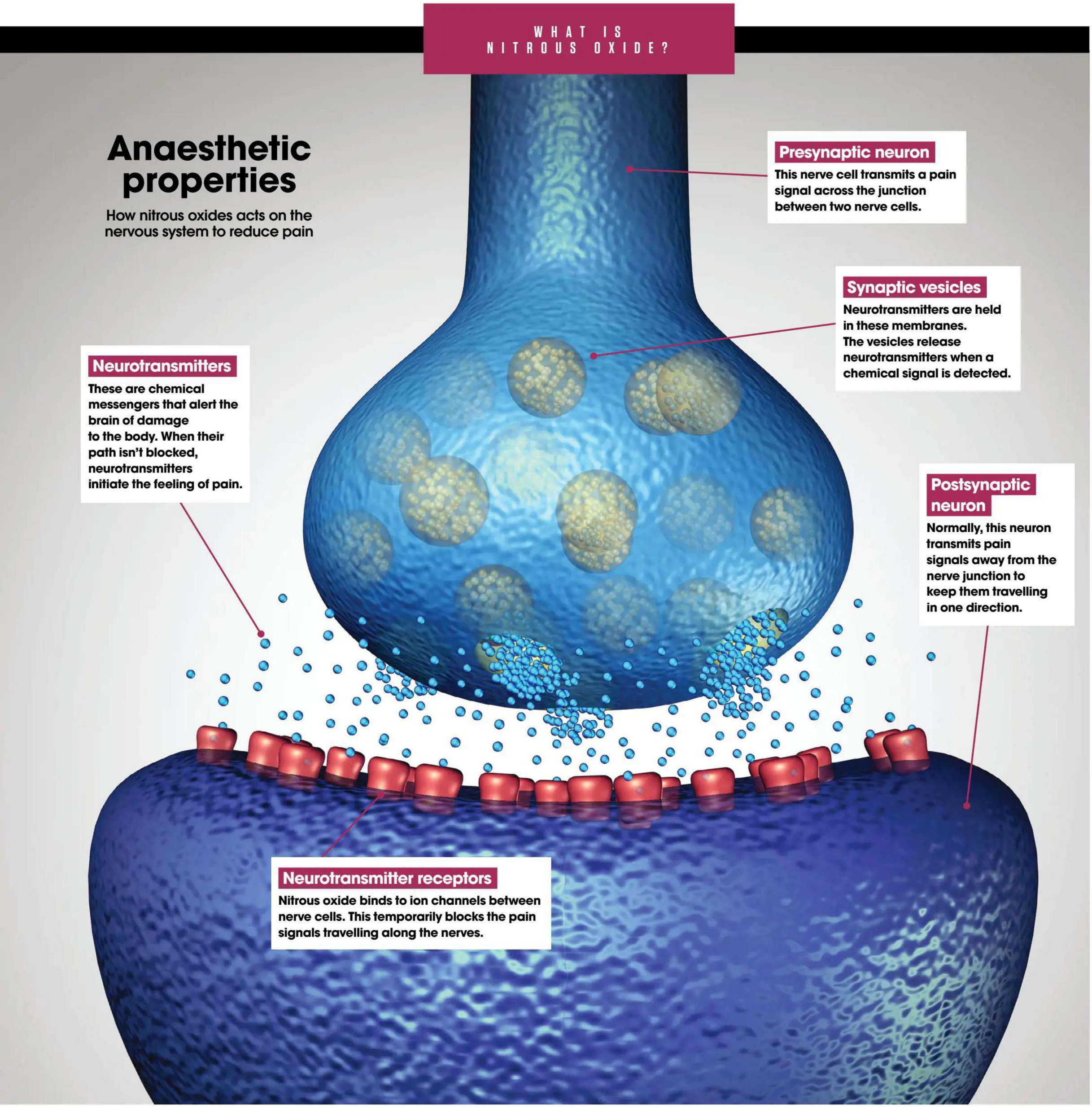
Nitrous oxide was first discovered by British scientist Joseph Priestley in 1772. While experimenting with air, Priestley successfully isolated oxygen and nitrous oxide, which he initially named 'nitrous air'. But the intoxicating and painkilling effects of nitrous oxide would be explored a couple of decades later by another British scientist, Humphry Davy. Davy spent many days heating ammonium nitrate crystals before collecting and inhaling the nitrous oxide that was released. Upon inhaling the gas himself and administering it to his friends, Davy found that it worked as a sedative and also caused euphoria. Davy acknowledged that the painkilling quality could be useful during surgical operations, but initially his findings just led to healthy people inhaling the psychoactive gas to entertain themselves at parties.



Humphry Davy nicknamed nitrous oxide 'laughing gas'

# Anaesthetic properties

How nitrous oxides acts on the nervous system to reduce pain




# Uses for NOS

### Medicine

Anaesthesiologists give patients 70 per cent nitrous oxide and 30 per cent oxygen to breathe during surgeries.

### Rocket motors

Nitrous oxide can be used in hybrid rockets. These use one solid rocket propellant and one gas. Another benefit of using the gas for rocket motors is that it's self-pressurising, meaning that its tank doesn't need to be repressurised as the fuel is used.

### Internal combustion engine

When it burns in an engine, it splits into nitrogen and oxygen gas. Engines running on nitrous oxide produce more oxygen by volume for combustion and the gas easily liquefies under pressure.

### Aerosol propellant

Laughing gas is used in many food products as an aerosol propellant. This includes cooking spray and whipped cream, as nitrous oxide doesn't break down the fats in these products.

### Recreation

Selling large quantities of laughing gas is illegal in many countries. Despite the dangers, some people still inhale nitrous oxide recreationally.

© Getty / Alamy

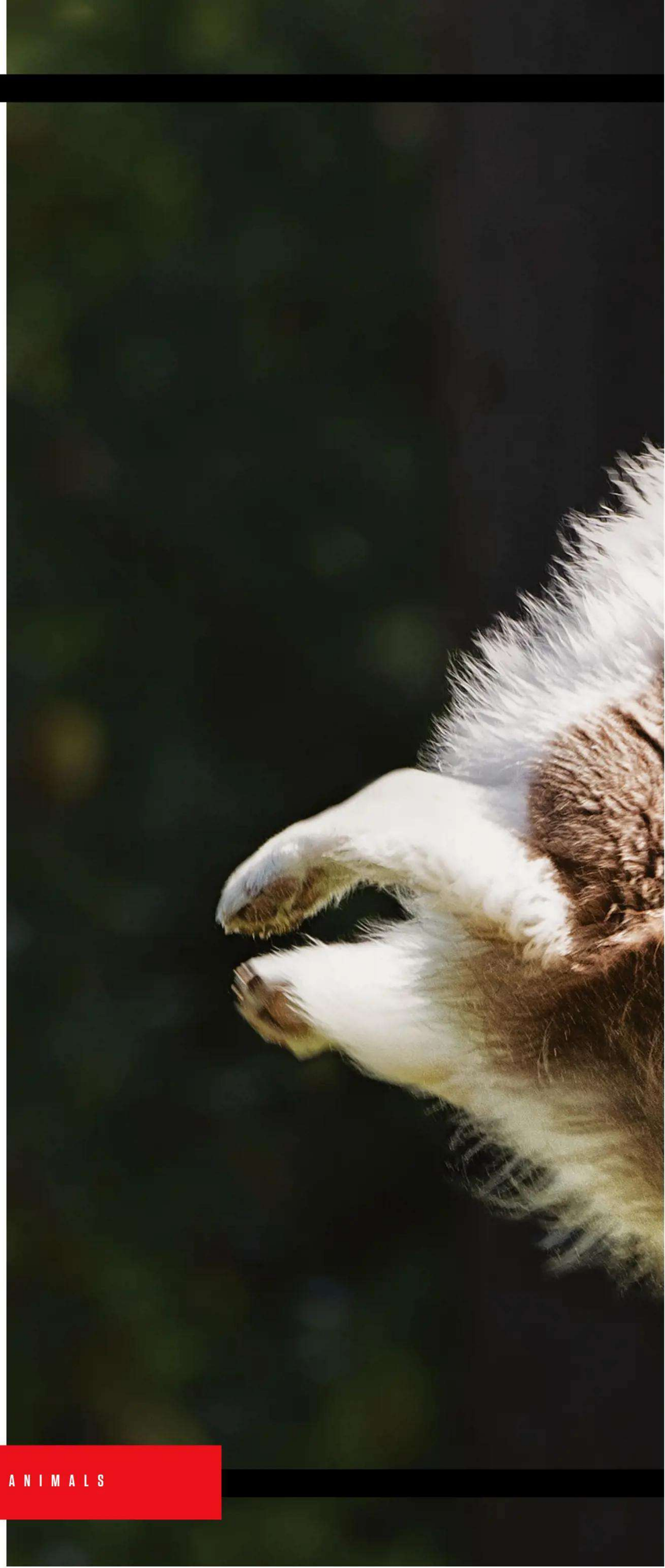
# Animals

# How to train your pet

*Explore the brains and behaviours of different animals for better pet-human communication*

It's almost every pet owner's dream to get on well with their animal and create a close bond. Each animal will think and process the world around them differently to humans, but by understanding your pet, you'll be able to better communicate, play and even dance together. Starting training with your pet in the early stages is essential for animals such as dogs, who need to learn how to live in the house and later be in public with their owner in a controlled manner. But training doesn't just make life easier for owners.

Studies show that animals that are exposed to regular mental stimulation from their human companions are more confident, trusting and coordinated. Training usually involves different levels of exercise, which is vital for most animals in keeping them fit and healthy while living mostly indoors. It's essential to remember that human concepts and ideas of what is 'right' and 'wrong' behaviour are mostly alien to pets until they are taught. Whether you want to teach your pet the basics or partake in entertaining routines together, patience and persistence are two of the most important qualities you will need to learn.



# The steps of animal training

**1**

## Association

At first, the word of a command will mean nothing to your pet. When first saying the command, demonstrate the action you wish the animal to perform through actions and pointing.

**2**

## Consistency

If there's more than one person living in your house, make sure you use commands and actions that match. A pet needs to receive the same information and expectations from everyone to learn quickly.

**3**

## Repetition

Your pet won't instantly catch on to different tricks and commands. Keep repeating the command until the word is ingrained and associated with the relevant action.

**4**

## Reinforcement

Try using an action that matches each command, such as tapping the back of a pet's body while saying "sit". This will serve as another prompt for each action to make the association stronger. When successfully achieved – with or without the prompt – reward with a treat.

**5**

## Maintenance

When you have achieved the desired level of training for your pet, maintain constant practice. Test their abilities daily if possible so that they don't forget over time.

© Getty

# The biology of obedience

How do different parts of a canine brain work during training?

**Parietal and occipital lobes**

Emotions and sensory information are decoded and processed in this section of the cerebral cortex.

**Cerebral cortex**

The main part of a dog's brain receives sensory information such as visual and audible commands.

**Frontal lobe**

A dog's alertness and intelligence is controlled in this area. Its memory for recognising and acting on commands it has previously encountered is determined here.

**Thalamus**

This central section of the brain works to keep a dog focused on one thing at a time, enhancing concentration during learning.

**Amygdala**

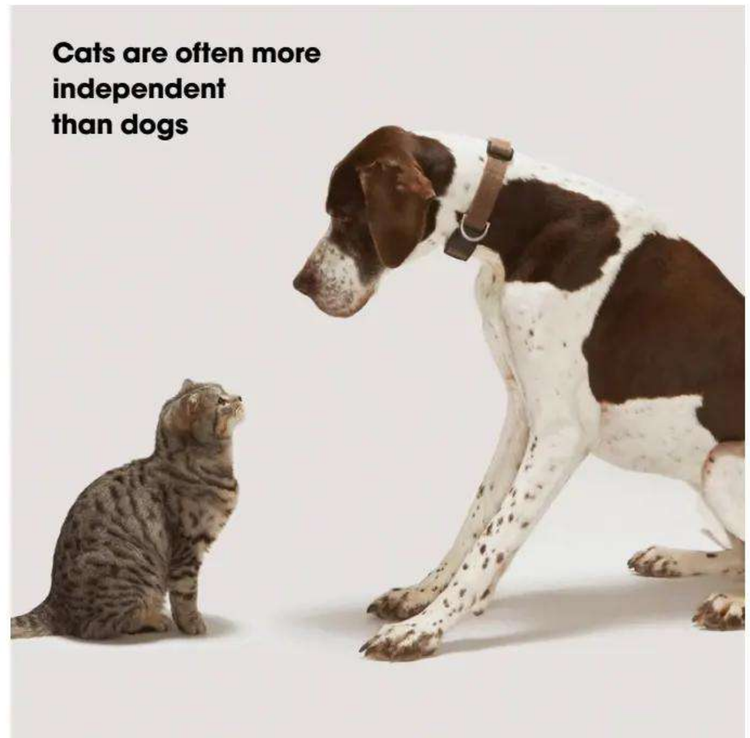
The amygdala processes emotions and connects them to a memory. This helps them remember the actions that gained them a reward.

**Hypothalamus**

Emotions like rage and aggression originate in this part of a dog's brain.

**Cerebellum**

This area controls a dog's voluntary muscle movements during training to achieve the requested positions.



Cats are often more independent than dogs

## Dogs vs cats

If you've ever tried to train both a cat and a dog, you're likely to have found the latter an easier task. But why is it that dogs will usually sit, while cats do as they please? In the wild, dogs are much more used to living in groups, and use their pack mentality instincts to adapt well to human commands. While dogs are naturally inclined to follow a leader, cats are more likely to act upon their own desires, regardless of what is suggested to them. However, cats do hold one great advantage in house training, as they are quick to associate litter trays as a place to go to the toilet. Dogs have 530 million nerve cells in the brain's cerebral cortex, whereas cats only have 250 million. This enables dogs to process more complex thought patterns and words, ultimately making them easier to train. Cats have tiny hairs in their ears that make them better listeners than dogs, but due to their desire to be accepted into a family, or pack, dogs are more likely to act on the commands they hear.

## Can pets talk?

Online videos of animals communicating with words are going viral. Videos show cats and dogs pressing buttons on a soundboard while their owners reply to them. The pets have a range of buttons they can press to play an audio recording of human speech. Each button plays a different word and requires owners to train their pet to associate the sounds with their meanings. One dog owner who has achieved a great deal of success with this is Alexis Devine, a user on the social media platform Tik Tok. She asks her dog Bunny questions, who responds with buttons. While these won't be full sentences, the combination of words makes it clear what the sheepadoodle is asking for, such as "more, food, now". There's even a video showing Bunny looking in the mirror before running to the buttons and pressing "who's this". After seeing the videos, scientists at the Comparative Cognition Lab at the University of California, San Diego have begun research, studying dogs, cats and horses to learn more about the capabilities of our pets' brains.

Soundboard buttons can be pressed to produce the words pets can't say

# Breed comparison

*Which dog breeds are typically the easiest or hardest to train?*

## Training champs

**Border collie**
**Intelligence**
This breed usually has relatively high energy and likes to be kept busy. Their high intelligence also means that they are quick to learn what is expected of them.

**Poodle**
**Obedience**
Poodles can begin to obey commands at just six weeks old. While their fluffy appearance is often what is first noticed about the breed, their looks are paired with natural athletic ability.

**German shepherd**
**Loyalty**
These dogs are some of the most willing to learn. For this reason they are often put to work as police dogs.

## Struggling students

**Beagle**
**Curiosity**
Beagles will explore everywhere, both in the home and out and about. This can make it difficult when training, as they can get easily distracted.

**Siberian husky**
**Active**
This breed needs regular long periods of exercise, as they were bred for endurance to pull sleds. They are known to be more mischievous if they are left too long and get bored.

**Chinese shar-pei**
**Territorial**
Families with children are discouraged from choosing this breed as they can be more unfriendly towards people than other breeds. This makes training a challenge – trainers are more likely to be seen as a threat.

# 5 Pet record breakers

### 1 Hamster athlete
**Fastest hamster racer**
Every year, competitive hamster racing takes place. The pets are placed in vehicles with a hamster wheel at one end. In 2001 the world record was set by the winner, covering the course in 38 seconds.

### 2 Cat trickster
**Most tricks in a minute**
Although cats are harder to train than dogs, it's still achievable. Cat owner Anika Moritz from Austria showed this in 2021 when she and her cat broke the record for the most tricks performed in a minute, demonstrating 26 different skills.

### 3 Rabbit baller
**Most basketballs dunked**
Bini the bunny rabbit, from Long Beach, California, holds the world record for the most basketball hoops scored in one minute. The rabbit is trained to pick up small basketballs in its mouth and release them through a miniature basketball hoop. Bini managed to dunk seven successive baskets in 2016, gaining the record.

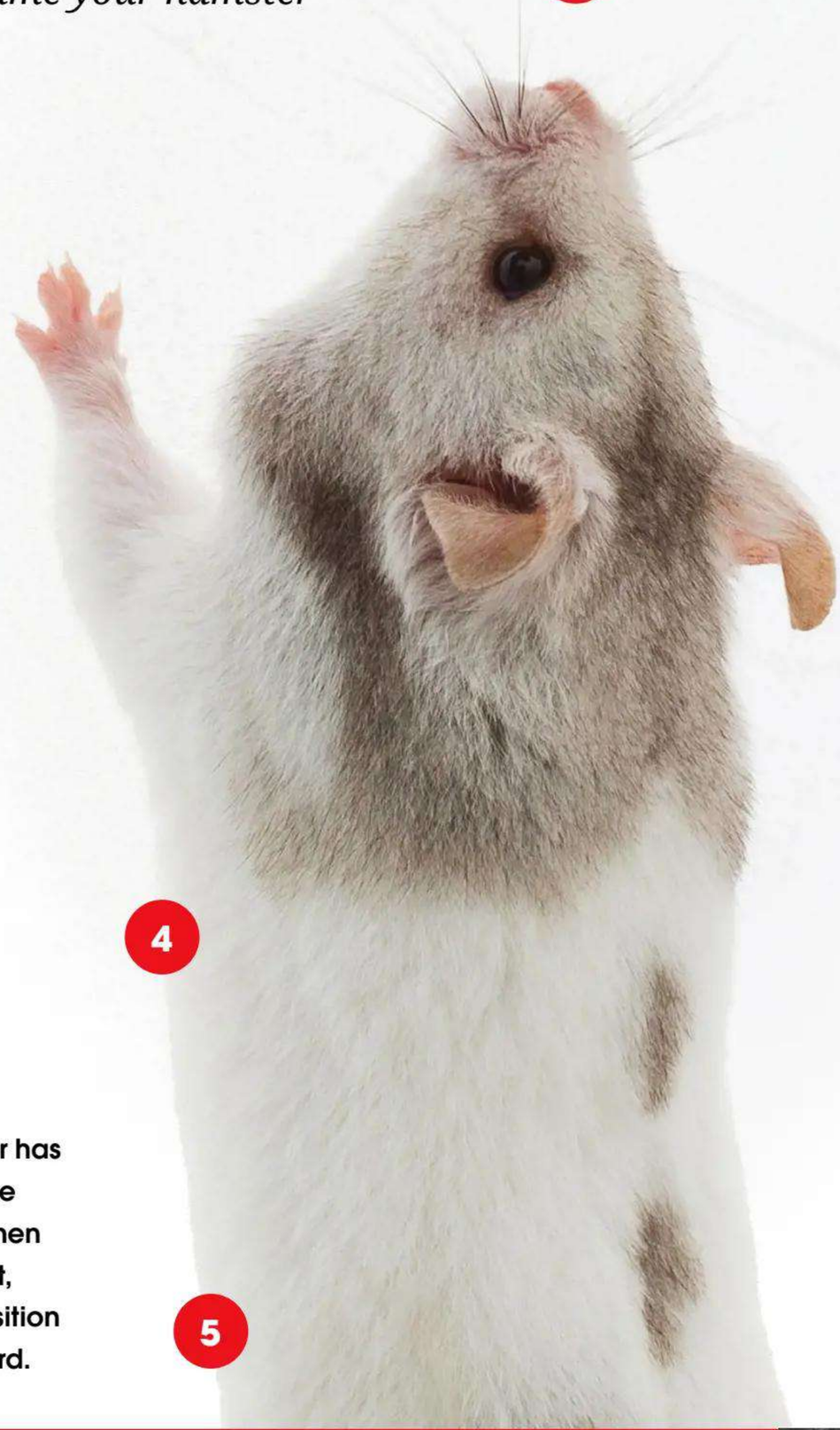
### 4 Chatty bird
**Largest vocabulary**
Speaking a total of 1,728 different words, the world record for the bird with the largest vocabulary belongs to Puck, a budgie from California. This skill was demonstrated in 1995.

### 5 Skateboarding dog
**Longest human tunnel ride**
Otto the bulldog was trained to skateboard through the legs of 30 people in a row to become the best skating dog in the world. Otto is from Lima, Peru, and wasn't led or touched during the skateboard ride.

© Getty / Science Photo Library

# Hamster handling

*These top tips will help you learn the best ways to tame your hamster*



**1 Placement importance**
For different tricks, you need to know what will help your pet perform an action. To teach a hamster to stand, place the treat directly above them.

**2 Getting close**
Before a hamster will follow your hand, it needs to be comfortable with it. Before performing tricks, place your hand gently and still on the cage floor to give your pet time to explore you first and get used to being close.

**3 Treat choice**
Nutritious treats such as seeds, fruits and vegetables are best for your hamster. Only give treats when it's earned, as it will become less of a treat the more that it's provided.

**4 Awake and ready**
Don't wake your hamster up to train; try training in the late afternoon and evening when they are naturally awake. These sessions should be short.

**5 Stand**
Wait until the hamster has performed the trick before saying the command. When the hamster is on two feet, say stand, so that this position is associated with the word.

## Syrian hamster: five training traits

What makes this type of hamster the most tame?

**1 Large size**
Being one of the bigger hamster species, Syrian hamsters are less skittish than others.

**2 Solitary**
Hamsters are usually solitary, but they often enjoy the affection from humans that they don't receive from other hamsters.

**3 Curious**
A Syrian hamster's ears are often upright to keep them alert, and they constantly explore their surroundings.

**4 Attachment**
Syrian hamsters like attention. When they gain your trust, they can actively seek attention from you.

**5 Active**
As active animals, Syrian hamsters need lots of exercise. This means that the exertion required for light training isn't too much for them.

## Animals with jobs

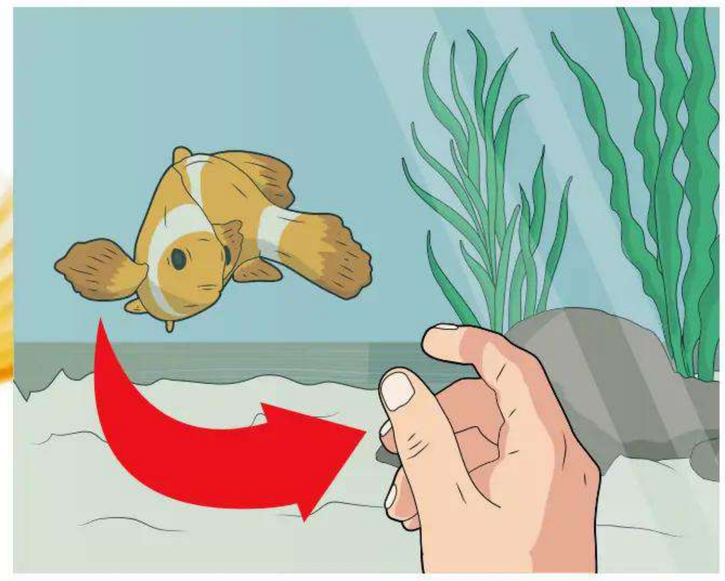
Some animals have been successfully trained to levels high enough to secure them a job. These jobs greatly benefit diverse groups of people on a daily basis. Service dogs, for example, are trained specially to suit the needs of those they will accompany. This includes guide dogs trained to navigate the world for blind people and keep them safe, service dogs who know to guard their owner when they experience seizures or dogs who are trained to distinguish between different sounds and alert their deaf owners.

Many animals learn niche skills for work in the military. Dolphins have proved trainable, using their underwater echolocation skills to seek out mines in the dark depths of the ocean. When it signals that it has spotted a mine, the dolphin is given a buoy that it places at the location for future reference and investigation.

This image shows a dolphin during military training

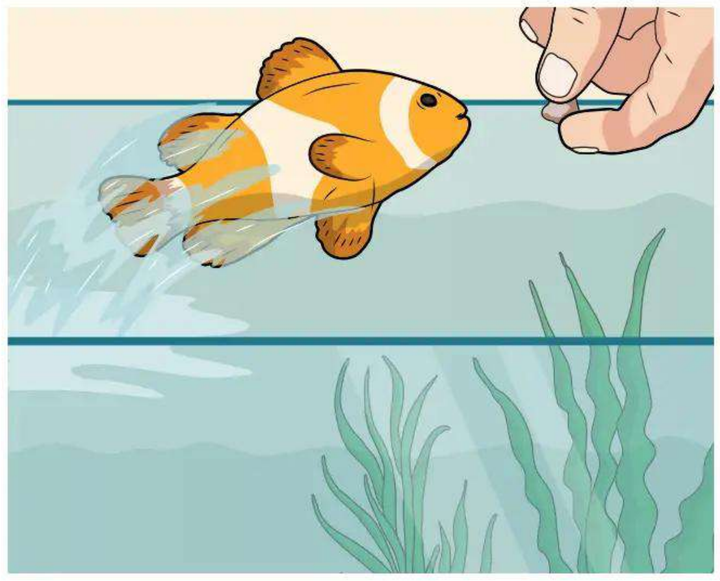
# Fish tricks

*Learn how to perform these impressive tank aquabatics with your fish*



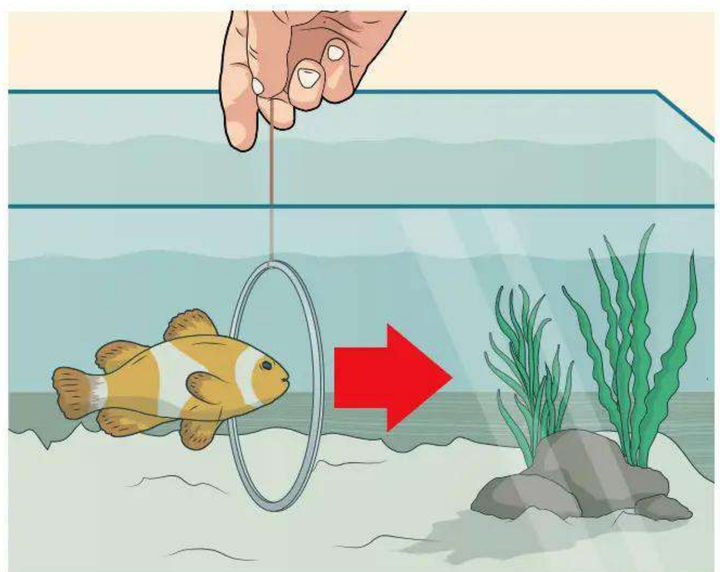
## 1 Finger following

The first step of any trick is to get the attention of your pet – in this case placing your finger in their eyeline on the outside of the tank will work. If the fish appears not to notice it, move your finger about. As soon as it acknowledges your finger, reward the fish with food instantly. Once it comes back to your finger, use the same technique while moving your finger along the tank. As soon as it successfully follows the finger, give the fish some food.



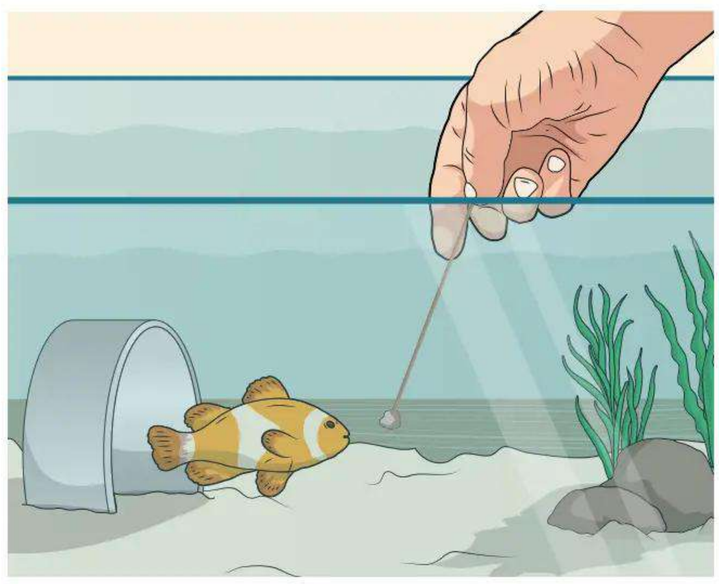
## 2 Air jump

Before attempting this trick, try feeding your fish by hand inside the tank so it will learn to trust your hand. Once your fish clearly makes this association, begin testing out a jump. Hold the food above the water instead of in the water until the fish notices. Place your fingers at the surface of the water, and when the fish swims close, pull up your hand away from it. Only when the fish successfully follows the food up into the air should you award it with food.



## 3 Swim through hoops

Using a clean hoop that's wide enough for your fish to fit through, tie a fresh piece of string to the top of it and dangle the hoop into the water. Make sure you are holding the hoop side-on to the edge of the glass and use the finger following trick to guide the fish through the hoop. After multiple successes, you can create hoop obstacle courses and introduce smaller and more challenging targets for your fish to swim through.



## 4 Obstacle course

If you think you've mastered single tricks, why not combine them? This can only be done when your fish has tried other tricks and knows its efforts will be rewarded. Using hoops, arches and other tank decorations, create an interesting course at the bottom of the tank. Instead of using a finger, attach a piece of food to the end of a stick and guide your fish along the route. If it only manages part of the course, start with a smaller one and work your way up to the full routine.

## Fish training biology

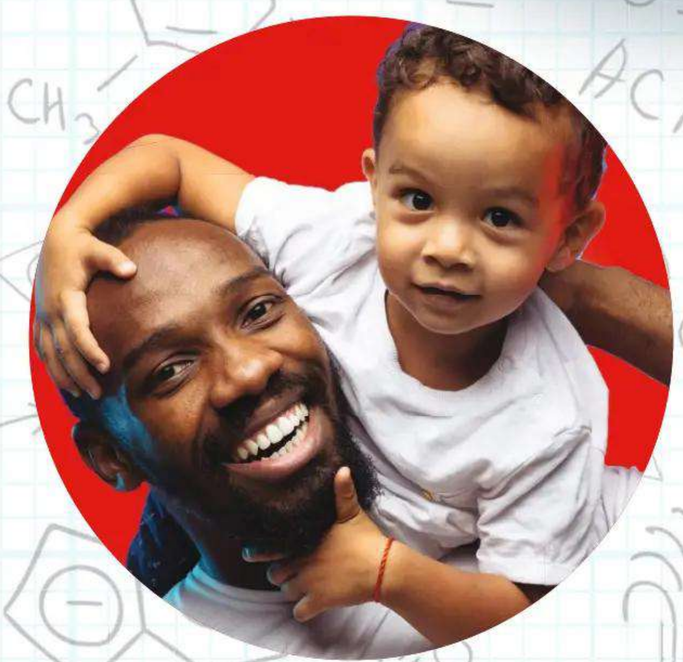
For you and your fish to become the perfect training duo, you need to understand how your pet sees and explores its surroundings. A fish is more likely to succeed in training if you use clearly visible targets. Fish can see colour, so you should use targets in a variety of different colours that stand out against your fish's tank environment. However, you can help your pet know where these targets are by keeping in mind how fish sense the world in other ways. Fish have an organ called the lateral line, which makes them very sensitive to sounds and vibrations in the water. When you have set a target, you might want to clap your hands near the target just before training. This not only alerts the fish to where you are, but also helps them associate a particular sound with training time.

A fish's eye has a wide field of view

© Getty / Illustration by Ed Crooks

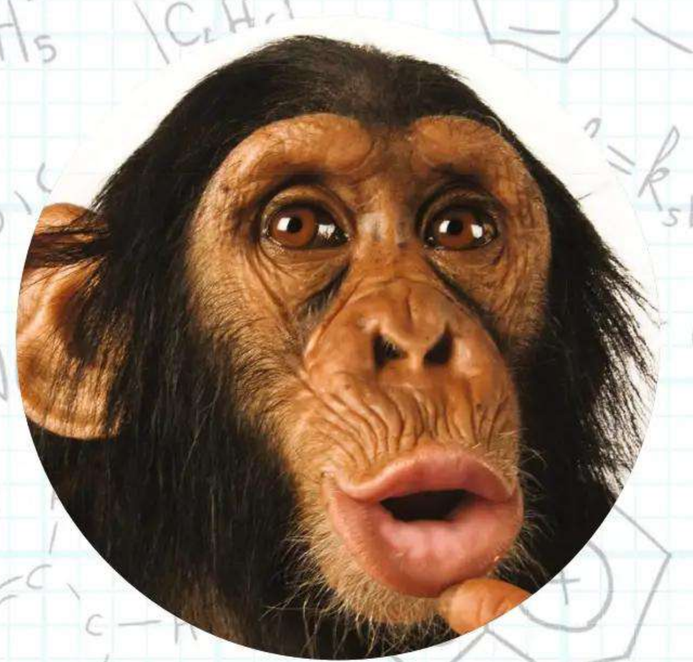
# Are you smarter than...

*How your intelligence compares to other clever members of the animal kingdom*



**Your Parents?**

**A Dolphin?**



**A Chimp?**

What makes you smart? At its most fundamental level, intelligence is often defined as a person's ability to learn from an experience, understand their environment and complete tasks. The fundamentals of intelligence have been broken down and pored over for hundreds of years, from the emergence of general intelligence, or the g factor, in the late 1800s to more recent explanations of its niche branches. Psychologist and Harvard professor Howard Gardner estimates that intelligence can fall into one of eight different categories. Each category covers the different ways humans process information, including musical, linguistic, naturalistic, spatial and interpersonal intelligence. A person may have more intelligence in one of these categories but may struggle in others. Whether you're particularly adept at solving puzzles, retaining factual information or gauging emotion, all these forms of intelligence come from the same place: the brain.

Within your skull is an organ that's so smart, it's the only organ in your body that perceives its own existence and has given itself a name. The average brain weighs around 14 kilograms, and it's made up of around 60 per cent fat. The rest consists of water, carbohydrates and proteins. To process thoughts and feelings and retain information and memories, the brain uses billions of cells called neurons. Neurons work together to form a vast network of active electrical impulses to keep your body ticking. Memories and cognitive abilities are held in the brain by forming connections of these neurons: the stronger the memory and the more information the neurons receive, the stronger the connection. To measure the strength of these connections and gauge

## A brief history of testing intelligence

### Binet-Simon Scale

French psychologists Alfred Binet and Theodore Simon were asked by the French government in the early 1900s to develop a test for school pupils to evaluate intelligence based on different tasks, such as copying patterns, naming objects and putting things in the correct order. The Binet-Simon scale was quickly adopted by psychologists and educators to standardise the measurement of intelligence.

### Stanford-Binet Scale

The Binet-Simon scale was adapted by Lewis Terman, an American psychologist at Stanford University, in 1916. Terman published The Measurement of Intelligence, which revised and broadened Binet and Simon's scale. The Stanford-Binet scale of intelligence quotient (IQ), as it became known, accounted for both a person's age, mental age and intelligence score to generate an overall IQ score.

### World War I admissions

In 1917, American psychologist and chair of the Committee on the Psychological Examination of Recruits for the US Army, Robert Yerkes, developed new IQ tests to assess the suitability of potential recruits into the armed forces. During this time, Yerkes assessed over 2 million soldiers.

### Wechsler Intelligence Scale

Developed by Romanian-American psychologist David Wechsler in 1941, the Wechsler scale applied a similar form of testing to the Stanford-Binet model, albeit longer and with fewer tasks. Rather than concluding with a single score, it calculated three: a person's verbal IQ, a performance IQ and finally a full-scale IQ.

© Getty / New York University

Different types of intelligence peak at different ages

**"One of the most commonly known intelligence tests of the modern day is the intelligence quotient test"**

human intelligence, many scientists and psychologists have created different 'intelligence tests'. Some of the earliest examples of mental tests date back 3,000 years to ancient China. One of the most commonly known intelligence tests of the modern day is the intelligence quotient (IQ) test. First developed in the early 1900s, an IQ test measures five categories to evaluate a person's cognitive ability. These categories include fluid reasoning, or the ability to think logically; general knowledge; quantitative reasoning, which uses mathematics to solve problems; visual-spatial processing and working memory. All of these elements of intelligence are individually tested, scored and then combined to get an overall IQ score. The average IQ score sits between 90 and 109, with anyone scoring above 140 considered to have a high IQ.

Over the years, some studies have made a positive correlation between the volume of a brain and the IQ score of its owner. For example, Albert Einstein's parietal lobes have been a sounding board for a genius with a big brain – his parietal lobes were 15 per cent larger than the average person's. The somewhat simplistic theory behind this idea is that a bigger brain has more neurons, and therefore can process and retain more information. However, not all scientists are sold on this idea, especially when you consider intelligence in the animal kingdom and among those that don't even have a brain, such as starfish. When it comes to sizing up who's smarter than who in the animal kingdom, sheer brain mass might not actually matter, especially not when you compare it to the animal's body size.

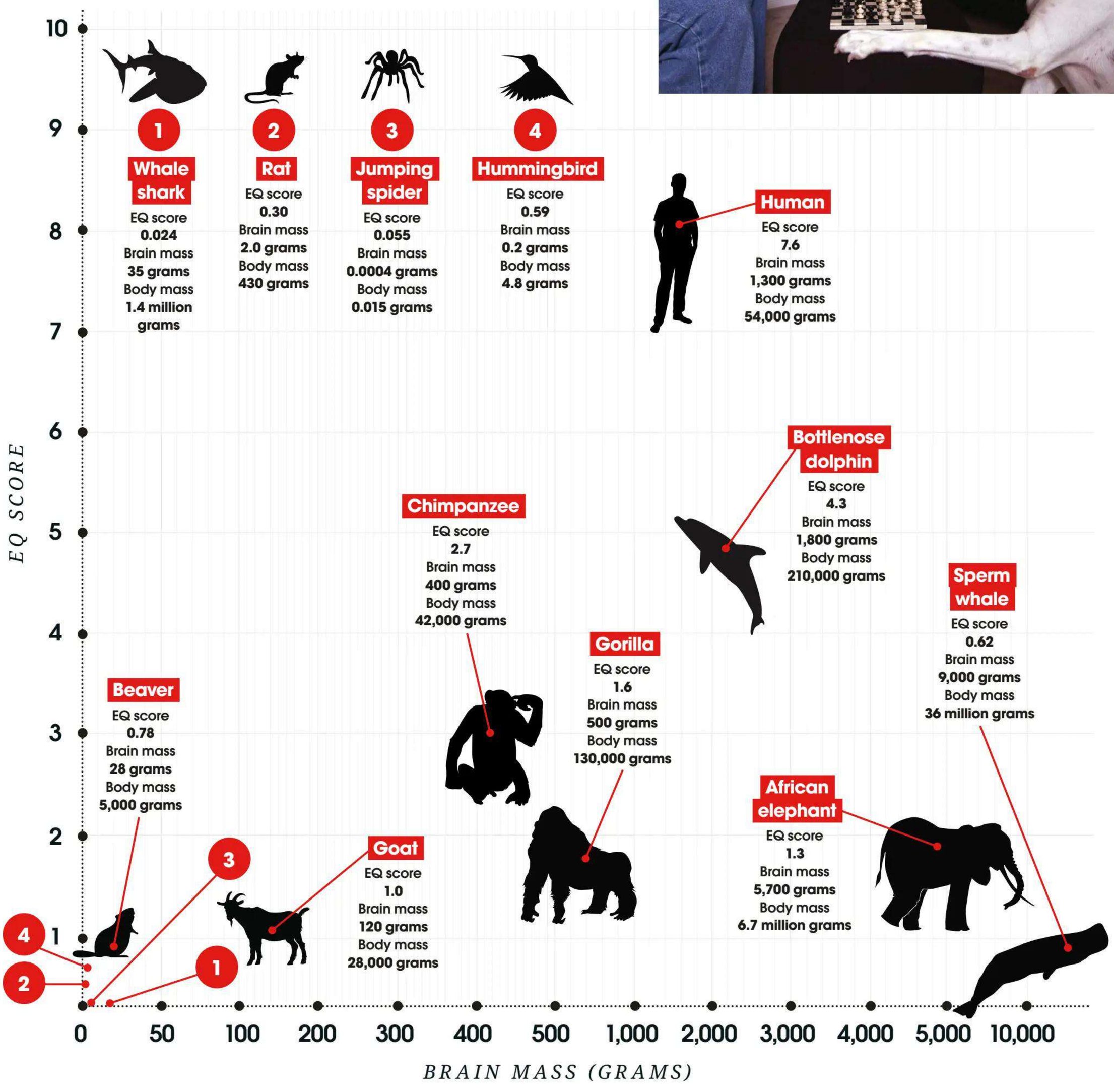
In 1973, psychologist Harry Jerison proposed a new metric to consider the relationship between the brain and body. Called the encephalisation quotient (EQ), Jerison said that calculating the ratio between an animal's body mass and brain volume could produce a comparative measurement of intelligence. Humans have an EQ score of between 7.4 and 7.8, which means human brain mass is over seven times greater than a typical mammal's. Much like any form of intelligence testing, EQ has faced criticisms and questions about its accuracy as a universal method to gauge an organism's overall intelligence.

## Are you smarter than your parents?

The ageing human brain is often associated with deterioration, memory loss and the development of neurological conditions such as dementia. While it's true that certain aspects of the human mind lessen in their functionality over time, intelligence doesn't necessarily decrease. A 2015 study by Harvard University revealed that different cognitive skills peak at different ages. Quick thinking and recalling information peak at 18 years old, whereas reading the emotions of others and event recall peak at 30. Other skills, such as basic maths and a broad vocabulary, don't peak until 50 years old. You might not be smarter than your parents in some aspects, but you are likely smarter than your distant relatives. Known as the Flynn effect, named after pioneering New Zealand intelligence researcher James Flynn, with every new generation, average IQ increases. It's estimated that with every decade, the average IQ score increases by three points. It remains unclear what the cause of this phenomenon is.

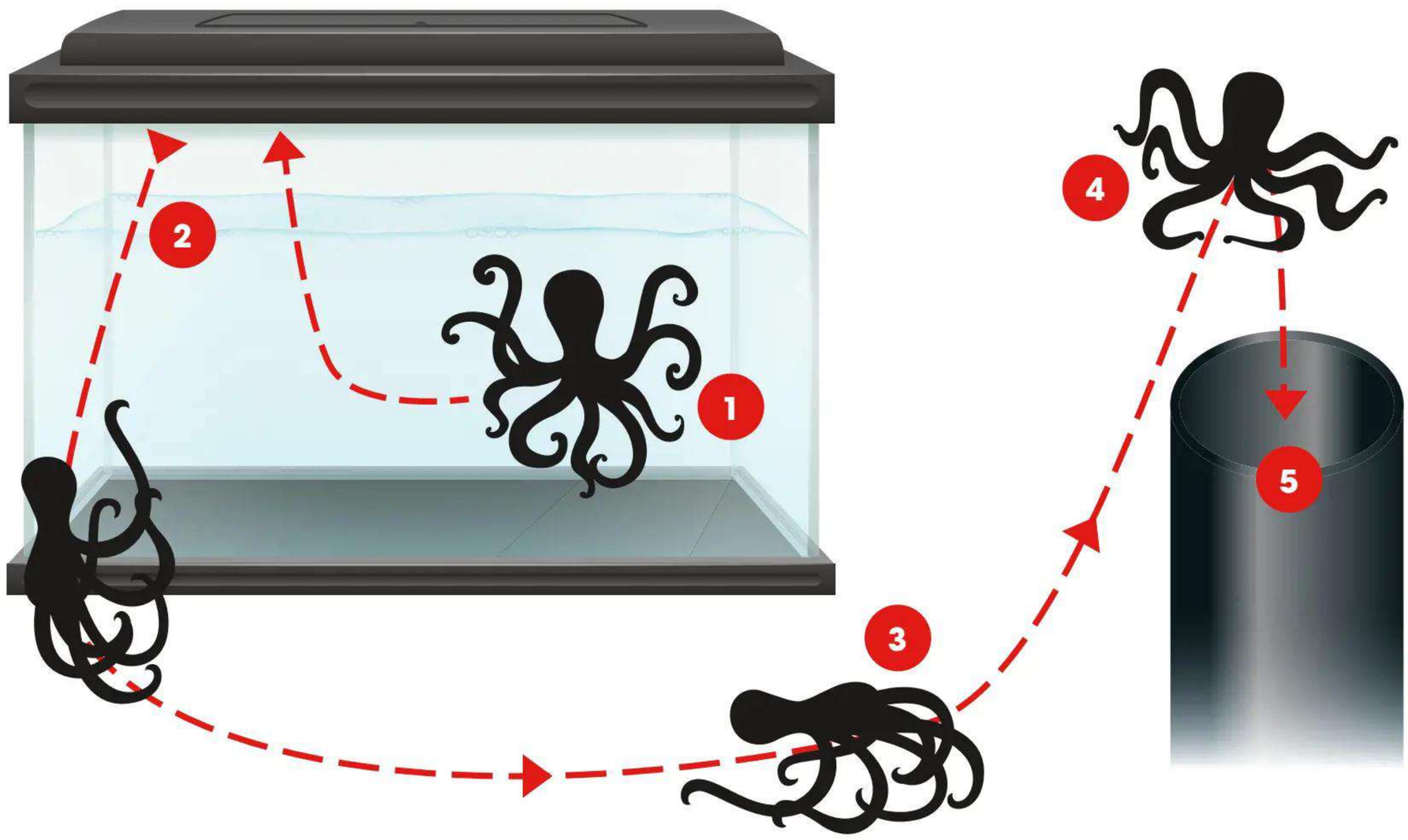
# Animal intelligence

*How EQ and brain size differ across the animal kingdom*




© Getty

# Clever critters




**1 Napier Aquarium**
Inky joined the National Aquarium in Napier in 2014 after a fisherman caught him in a net from Pania Reef.

**2 Escape hatch**
Thanks to its malleable body, Inky easily slipped through a small gap at the top of the tank, around two metres off the ground.

**3 Eight-legged it**
Inky then made a run for it along the aquariumfloor for a further two to three metres.

**4 Freedom**
On the other side of the floor was the entrance to a drainpipe that led directly to the ocean.

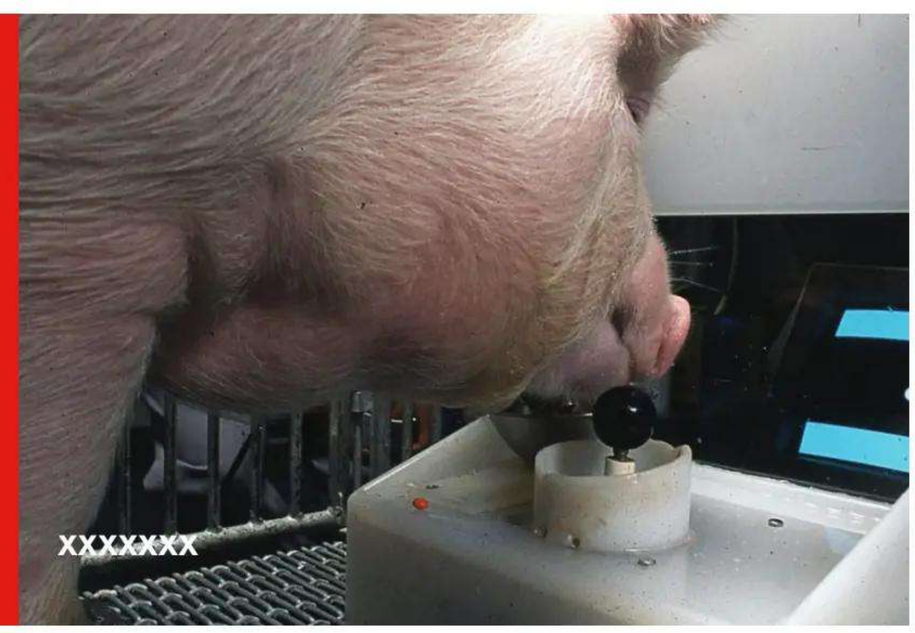
**5 Vanished**
Inky did not return to the aquarium, leaving his fellow octopus tank mate Blotchy behind.

## Octopus escape artists

Octopuses, of which there are around 300 species, are brainboxes with a talent for escaping. Unlike other mollusc species, octopuses have a centralised brain similar to a human's. However, only a third of its overall neurons can be found in its brain. The rest can be found in the octopus' arms. Over the years, many octopuses in captivity have wreaked havoc on their keepers with their escape artist antics. In 2016, an octopus named Inky sprung itself from a New Zealand enclosure, Finding Nemo-style, and into a 50-metre drainpipe that led to the ocean. Similarly, in Bermuda an octopus temporarily escaped its tank to eat the crab inhabitants of the adjacent tanks before returning to its own enclosure.

### Piggy gamers

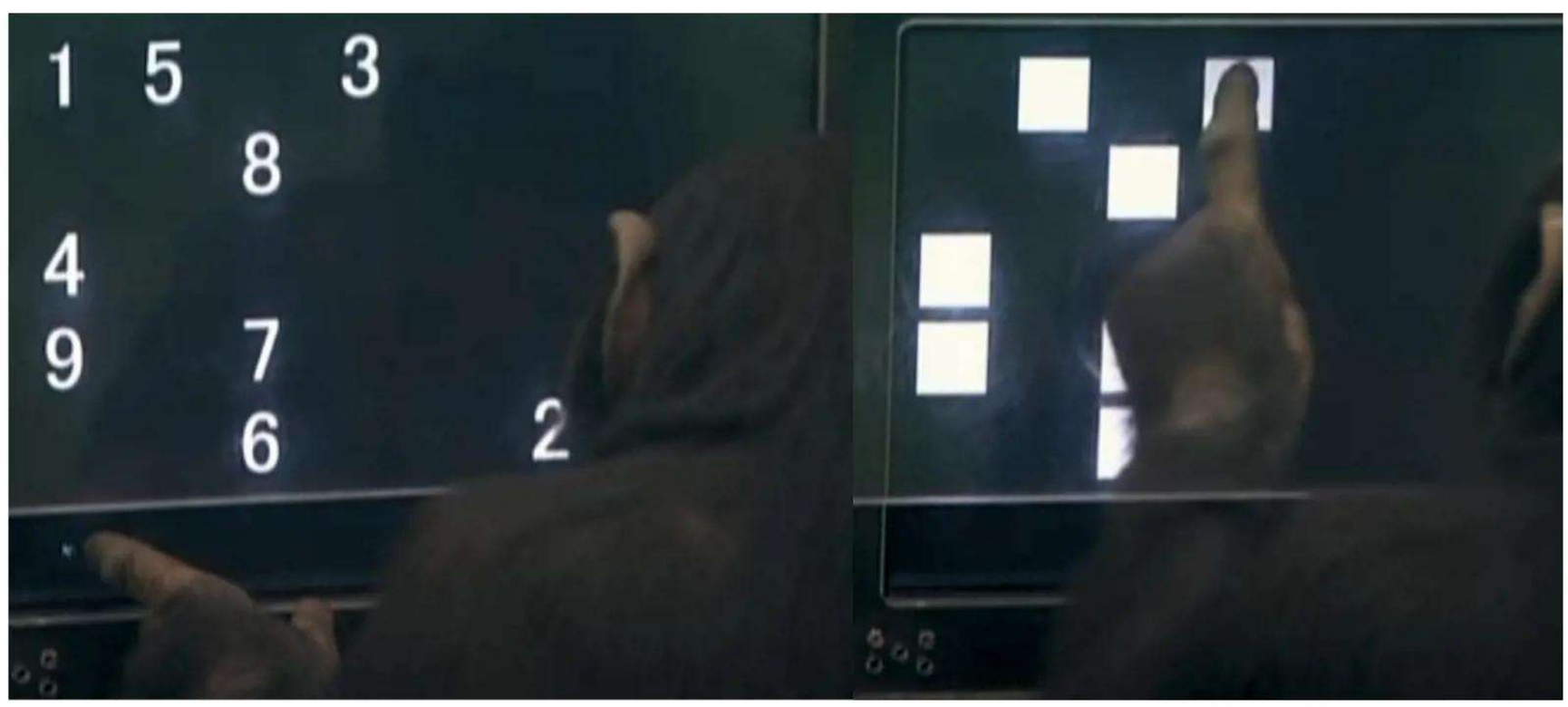
The intelligence of pigs has been well documented over the years. In puzzle-solving studies, researchers discovered that pigs can locate and flip containers holding tasty treats quicker than dogs and persist longer in the trials of unsolvable puzzles. Pig smarts have also been challenged in the gaming world. Researchers at Pennsylvania State University trained four pigs, called Hamlet, Omelette, Ebony and Ivory, to use arcade-like joystick games. The pigs used a joystick to move a cursor on a digital screen to hit walls, and some were better than others: Ivory hit one-wall targets 76 per cent of the time. However, Omelette and Hamlet only hit the targets less than half of the time. To keep the pigs engaged with the game, a food reward was dispensed after 'winning'. During this investigation the dispenser broke, but the pigs continued to play on without any rewards.



A New Caledonian crow using a twig to fish for grubs

# Crow engineers

Corvidae is a family that includes crows and ravens, which are among the cleverest birds on Earth. They are particularly good at solving puzzles and finding a solution to a problem, especially when food is involved. It's been well documented that crows, particularly New Caledonian crows (Corvus moneduloides), use small twigs to hook into holes in tree bark to fish out insect meals. Researchers at the University of Oxford have discovered that New Caledonian crows can construct tools to snatch food in hard-to-reach places. Researchers initially gave crows sticks long enough to dig out treats from a transparent puzzle box, which they completed easily. When researchers introduced items such as dismantled plastic syringes that alone were too short to reach the food, the crows quickly came up with a solution. By partially inserting the plunder of the syringe into the accompanying barrel, they created tools long enough to reach the food and move it out of the puzzle box.




# Can you outsmart a chimp?

As our closest evolutionary relative, chimpanzees are some of the smartest animals on Earth. Along with using tools and heightened emotional intelligence, these primates have remarkable memory and cognitive functions. Researchers at the Primate Research Institute at Kyoto University, Japan, conducted a landmark study that demonstrated the ability of chimpanzees to recognise and recall information. Ayumu, one of the test chimps, was shown numbers one to nine in random positions on a touchscreen. The goal of the task was to touch each of the numbers in ascending order. Once Ayumu hit one, the others became white boxes, forcing him to remember the order and positions of the other numbers on the screen. Remarkably, Ayumu and humans scored the same 80 per cent degree of accuracy in recalling their order and positions. The test became increasingly difficult, up to a numeral range of one to 19, and the two-digit structure of single numbers ultimately proved too difficult to recall for Ayumu.

**Scan here**
or use the link to find out if you have a better memory than a chimpanzee
**HUMANBENCHMARK.COM/TESTS/CHIMP**

## 5 Animal tool users

### 1 Sea otters
While floating on their backs, sea otters (Enhydra lutris) use stones to hammer at abalone shells and crack them open to eat the sea snails.

### 2 Macaques
Although flossing isn't the biggest concern among apes, researchers have found that some macaques use human hair as dental floss.

### 3 Orangutans
As keen music makers, Bornean orangutans (Pongo pygmaeus wurmbii) gather leaves and twigs to form a musical instrument to alter their call and ward off predators.

### 4 Elephants
From fly swatters to weaponry, elephants have found many uses for tree branches. Observations of African elephants revealed that they use heavy pieces of wood to lower fences to climb over them.

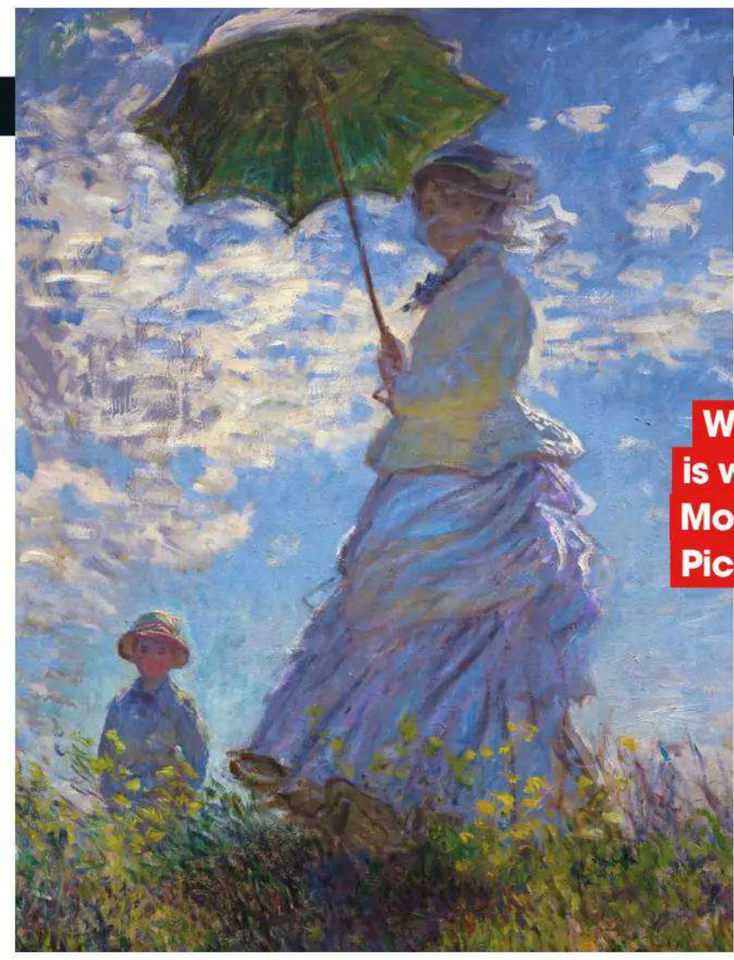
### 5 Shrikes
As fierce hunters, these cute, fluffy birds use sharp twigs and branches to spear their prey. Once they catch a mouse, snake or even another bird, shrikes impale them to create a macabre larder where they can feast on their prey over time.

© Getty / Primate Research Institute, Kyoto University / Pennsylvania State University

## Parrots have similar brains to people

If you've ever spent time with a parrot, you'll know they are intelligent birds. Many species have the ability to mimic speech and solve complex puzzles. They can even understand the concept of zero, much like humans. In fact, research has shown that parrots and humans share regions in their genomes that regulate the development of the brain. For humans that set of genes led to us growing bigger and more complex brains than our primate ancestors. Similarly for parrots, they possess some of the biggest brains among all birds.

Scientists at the University of Alberta, Canada, have found similar neural circuitry in both parrot and primate brains. Two of the largest parts of the brain are the cortex and the cerebellum, which are both responsible for vital higher cognitive functions, including motor skills and information processing. There's a cerebral bridge between the two called the pontine nuclei that ferries information and plays a major part in the overall intelligence of primates. Parrots have a much smaller pontine nuclei than primates, but researchers found that these birds have a similar structure, called a medial spiriform nuclei, that appears to function in a similar way to primates' pontine nuclei. The researchers concluded that an enlarged spiriform nucleus enhances the connection between the cortex and the cerebellum, leading to higher cognitive functions.



Which is which: Monet or Picasso?

# Avian art dealers

Researchers at Keio University in Japan put pigeons to the test to see if they were able to make a distinction between the two artists' work. To do this, pigeons were trained to peck at an illuminated glass screen. The birds were divided into two groups: one was rewarded with hemp seeds when they saw Monet paintings behind the screen, while the other group was rewarded when Picasso's work appeared. By the end of the experiment, both groups could identify the work of their artist to an accuracy of over 90 per cent. Even when the paintings were shown in black and white, the birds still maintained this level of accuracy. This shows that the birds recognised the style and structure of the artist's paintings, not just the colours.

# The cleverest animal on Earth

Dolphins have been recognised as the smartest non-humans on Earth. Bottlenose dolphins have the biggest dolphin brains – they average around 1,600 grams, compared to an average 1,300-gram human brain. However, a dolphin's EQ score is the second largest among animals, surpassed only by humans.

One of the most remarkable aspects of this animal's intelligence is self awareness. Researchers at the Rockefeller University, New York, tested the capacity for mirror self-recognition in bottlenose dolphins to gauge their self-awareness. Using a temporary non-toxic black ink marker, scientists either marked, pretended to mark or ignored their dolphin test subjects and placed mirrors in their swimming tank. What they discovered was that marked dolphins, and even those that thought they'd been marked, spent more time engaging in 'self-directed' behaviours in front of reflective surfaces. The study findings suggest that the dolphins used the mirrors and reflective surfaces to investigate the markings on their bodies. Dolphins aren't alone in their self-awareness. Elephants, orangutans and even ants can spot themselves in a mirror. However, combined with their big brains, a dolphin's social and communication skills put them at the top of the class.

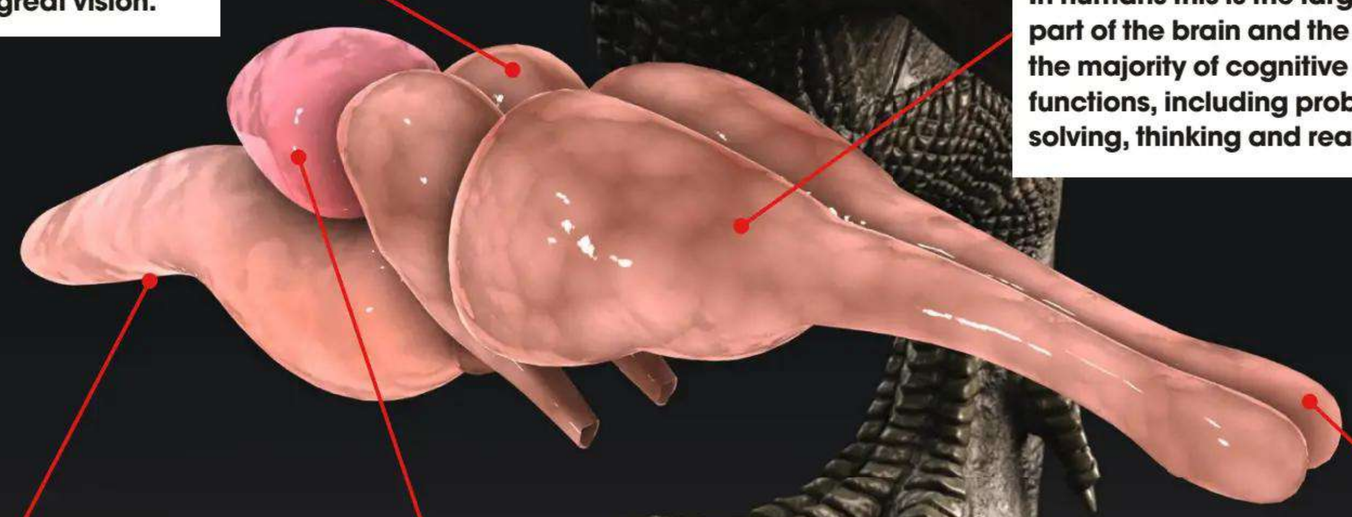
**A bottlenose dolphin recognising its own reflection in a mirror**

# Was the T. rex dumb?

Researchers at Keio University in Japan put pigeons to the test to see if they were able to make a distinction between the two artists' work. To do this, pigeons were trained to peck at an illuminated glass screen. The birds were divided into two groups, one of which was rewarded with hemp seeds when they saw Monet paintings behind the screen, while the other group was rewarded when Picasso's work appeared. By the end of the experiment, both groups could identify the work of their artist to an accuracy of over 90 per cent. Even when the paintings were shown in black and white, the birds still maintained this level of accuracy. This shows that the birds were able to recognise the style and structure of the artist's paintings, not just the colours.

## Inside a T. rex's skull

The brain behind the fiercest prehistoric predator




It's a common misconception that the T. rex was stupid

© Alamy / Getty

# Can you beat the How It Works team?

*Put your IQ to the test with these perplexing puzzles and see how you compare against team How It Works. You've got 15 minutes, starting... now!*

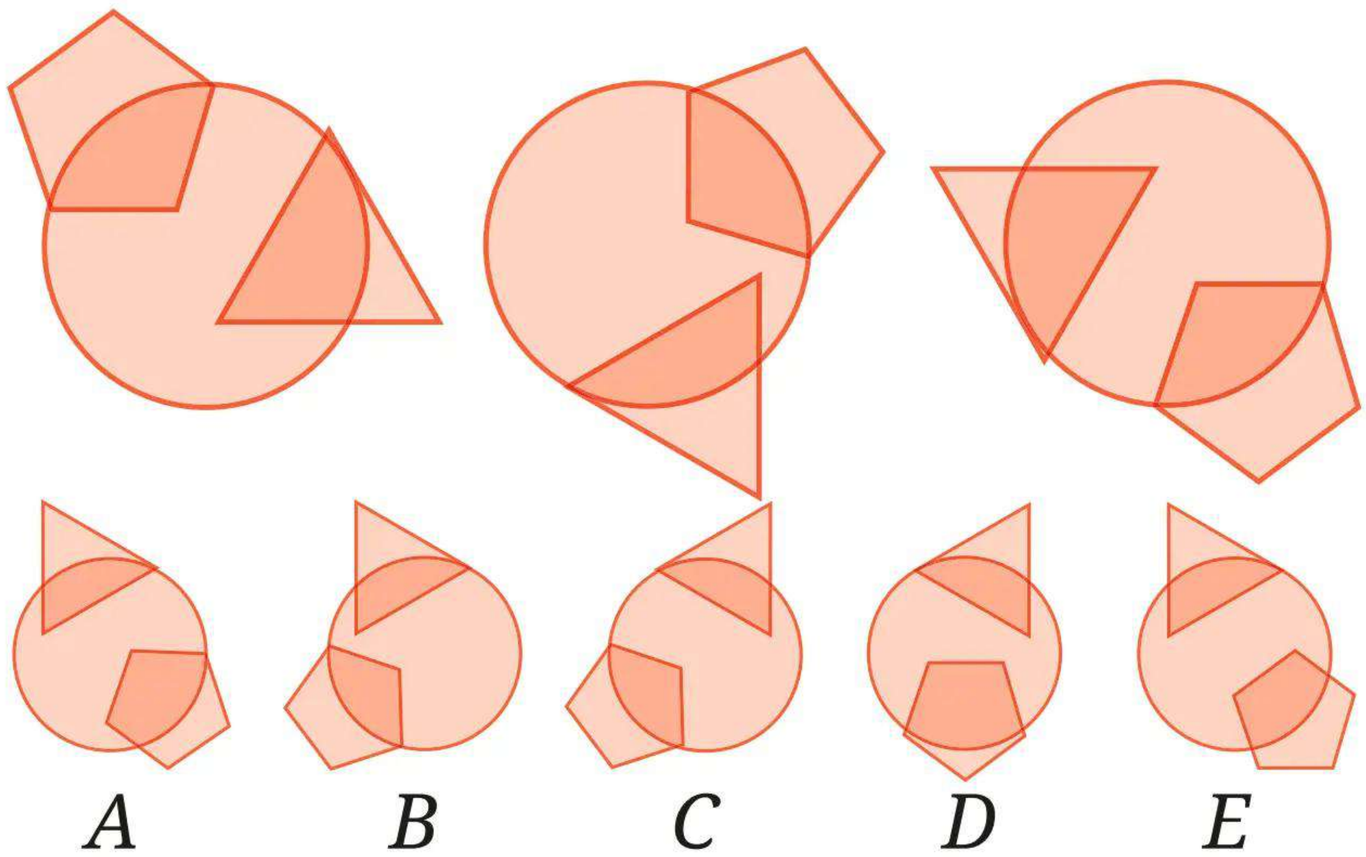
## 1

Fill in the missing plus, minus and multiplication signs to make the equation below correct, performing all calculations strictly in the order they appear on the page.

32 28 4 21 7 18 = 36

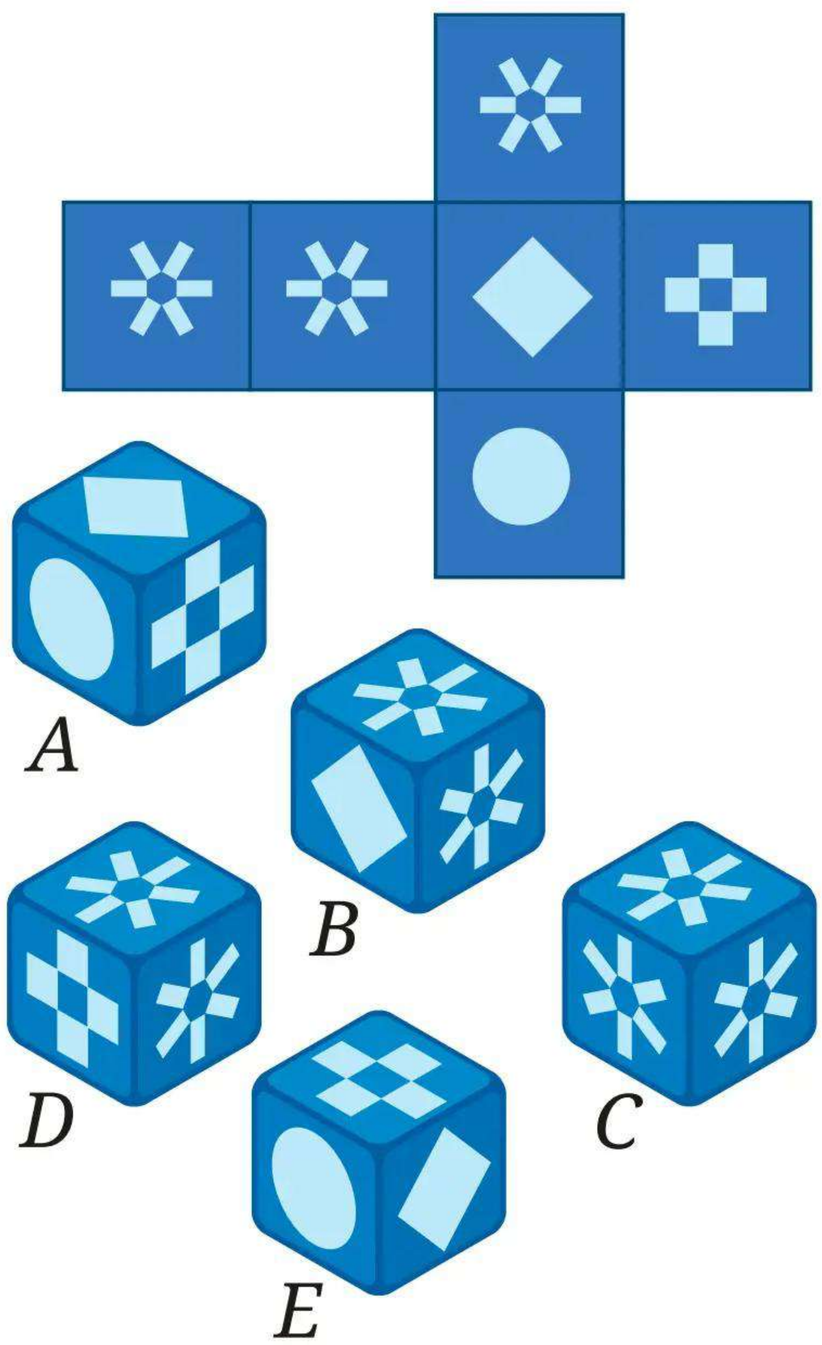
## 2

Which of the options A to E most accurately continues the sequence?

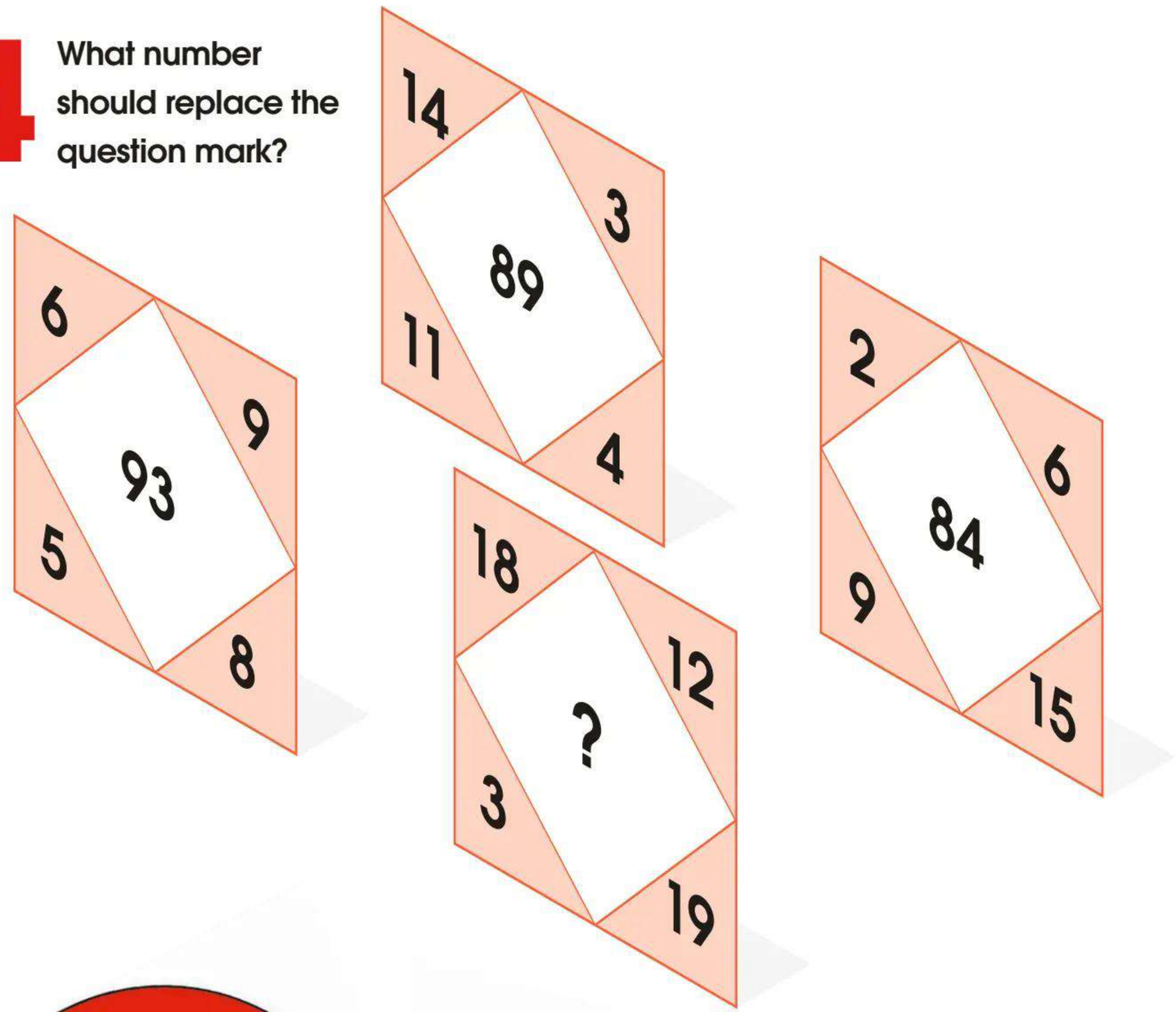



## 3

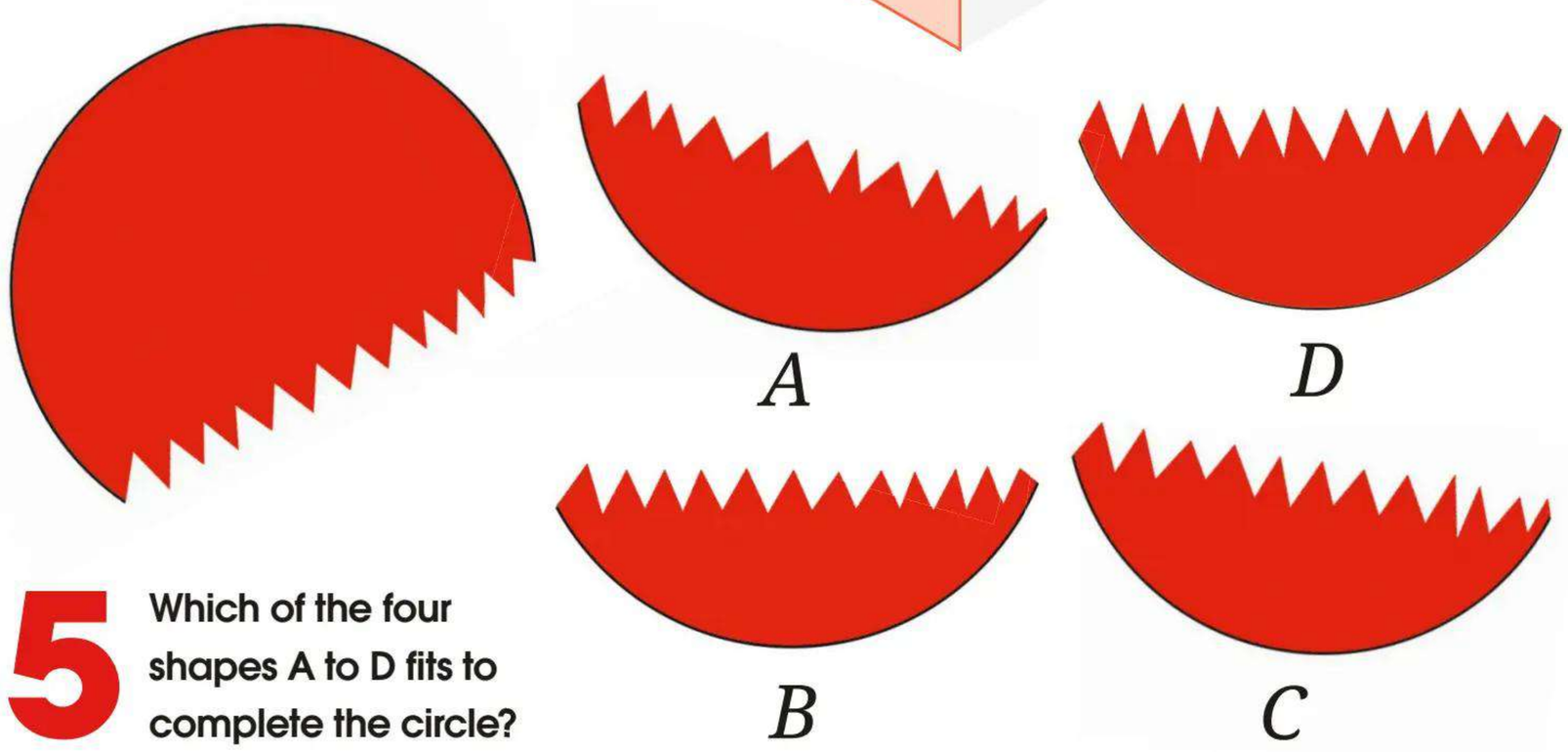
Which of the cubes A to E cannot be made using the layout shown?



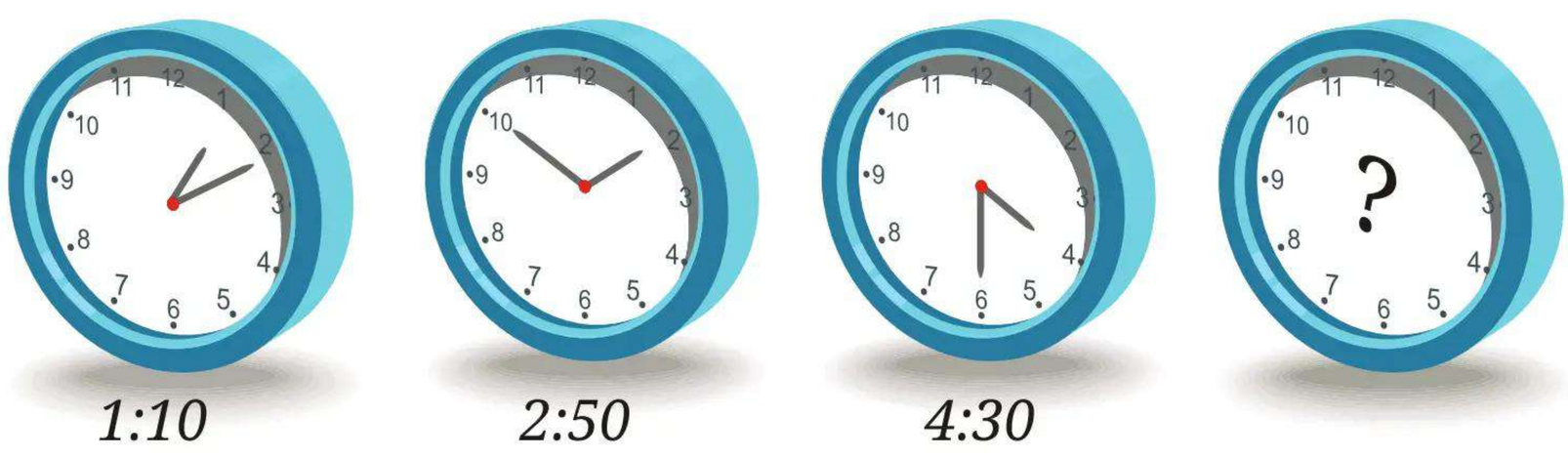
## 4 What number should replace the question mark?




## 5 Which of the four shapes A to D fits to complete the circle?




## 6 What time should the final clock indicate?




## Beat the team results

**Nikole**

**6/6**

Despite her modesty about taking this test, Production Editor Nikole topped the team with full marks. You'll do well to match her

**DUNCAN**

**5/6**

There must be something about dealing with pictures that gives Senior Art Editor Duncan the edge in this visual IQ test.

**Ailsa and Scott**

**4/6**

Writers Scott and Ailsa draw level with two-thirds accuracy. You can pat yourself on the back if you score four out of six too.

**Tim**

**3/6**

Shows that being the boss doesn't make you smarter than everyone. Except if you're the Editor-in-Chief who's bossing the Editor Ben.

**Ben**

**2/6**

You'd think, being Editor and all, Ben would give himself a high score. Two out of six in this tough challenge isn't all that bad.

### Answers

**Puzzle 1:** 32-28x4-21+7x18=36

**Puzzle 2:** B (group rotates 90 degrees clockwise, then triangle rotates 180 degrees)

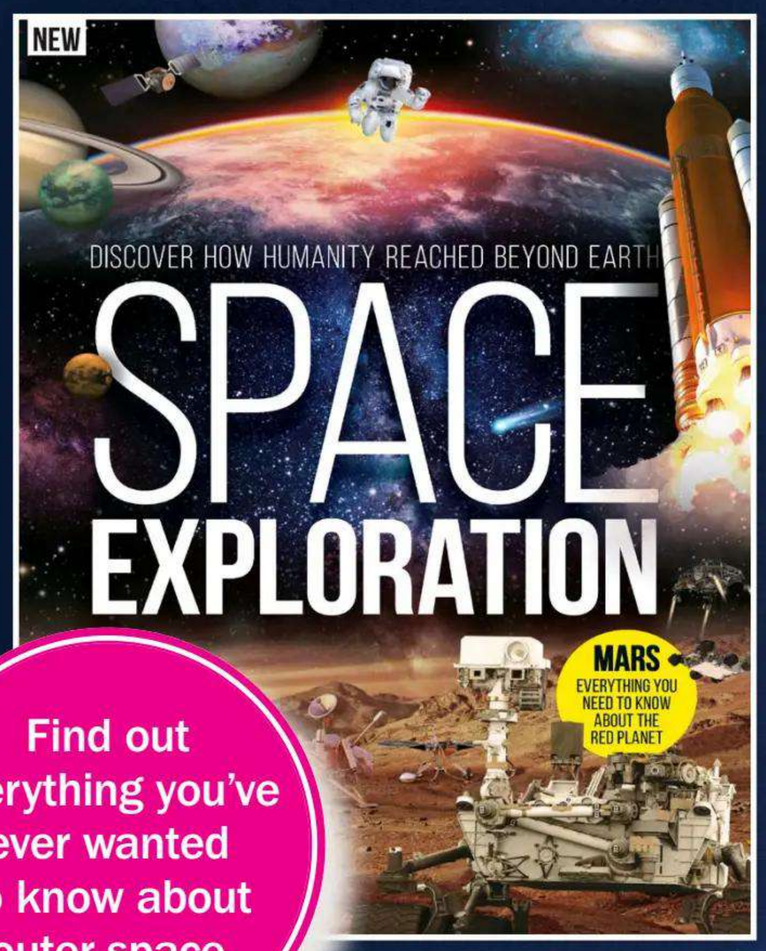
**Puzzle 3:** E

**Puzzle 4:** (18x19)+(3x12)=342+36=378

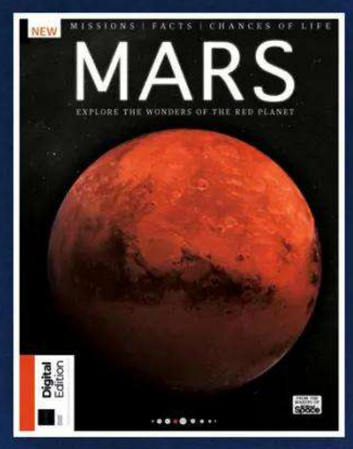
**Puzzle 5:** B

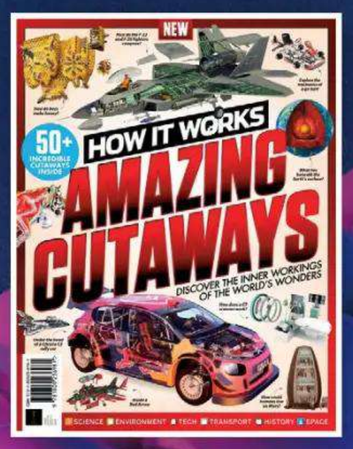
**Puzzle 6:** 4:30+1:40=6:10

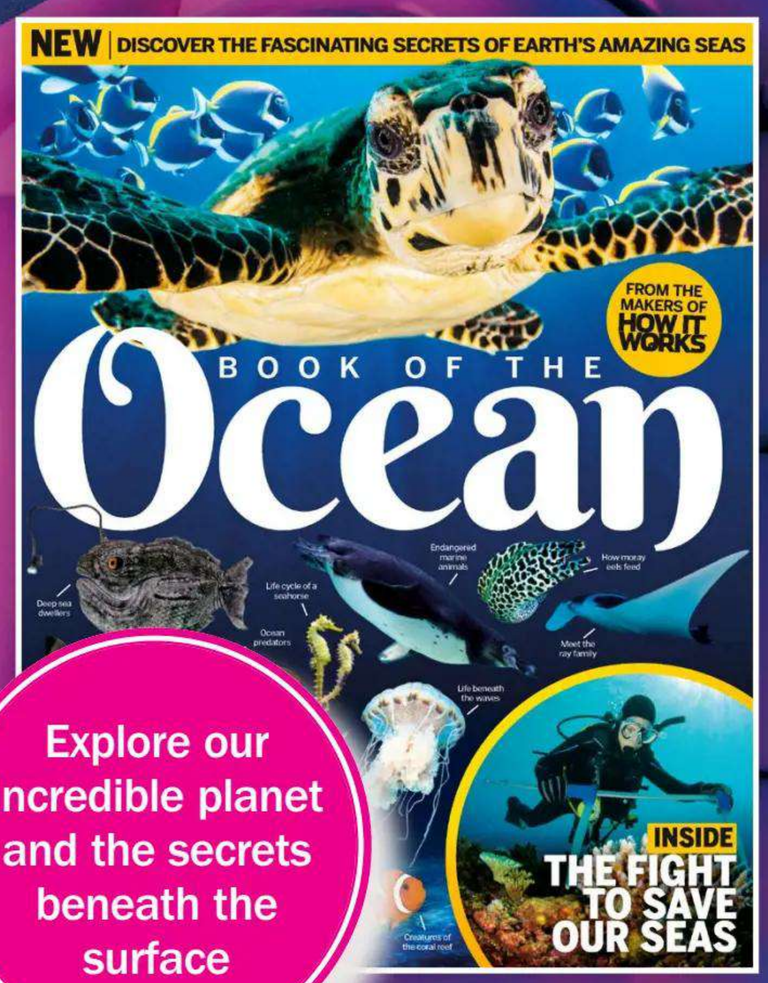
© XXXXXX



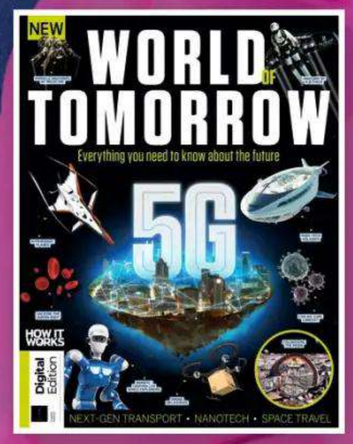

Find out everything you've ever wanted to know about outer space

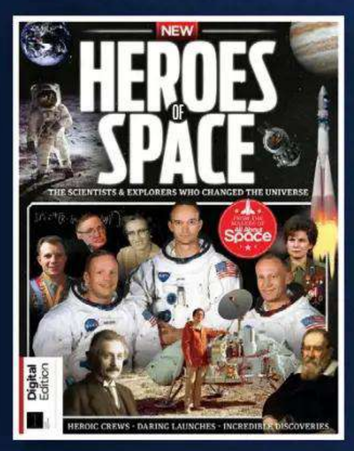


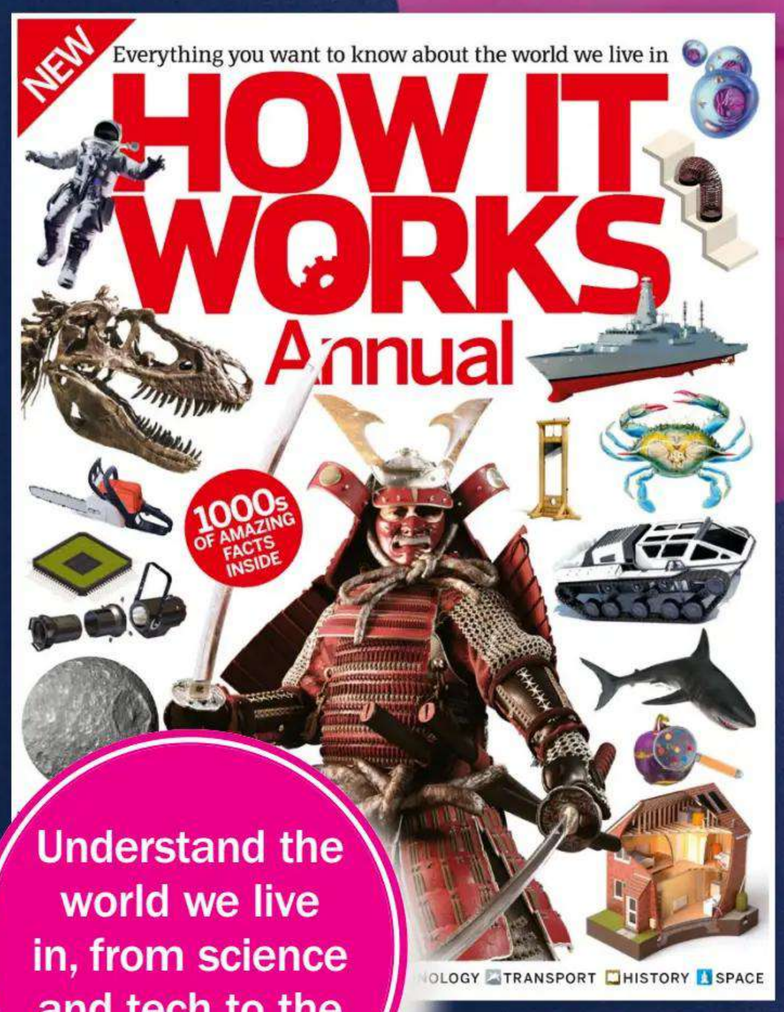




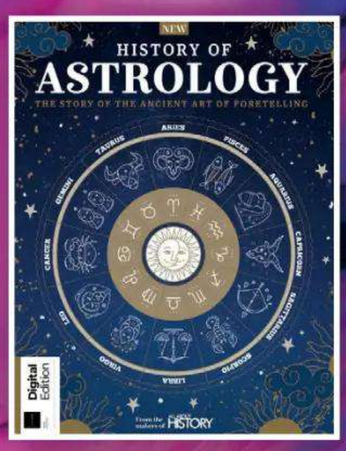

Explore our incredible planet and the secrets beneath the surface

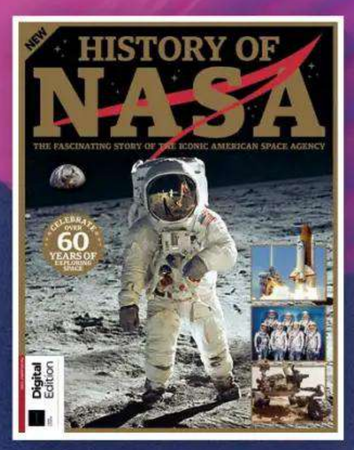



Understand the world we live in, from science and tech to the environment

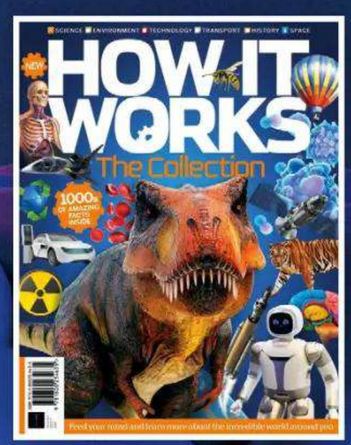


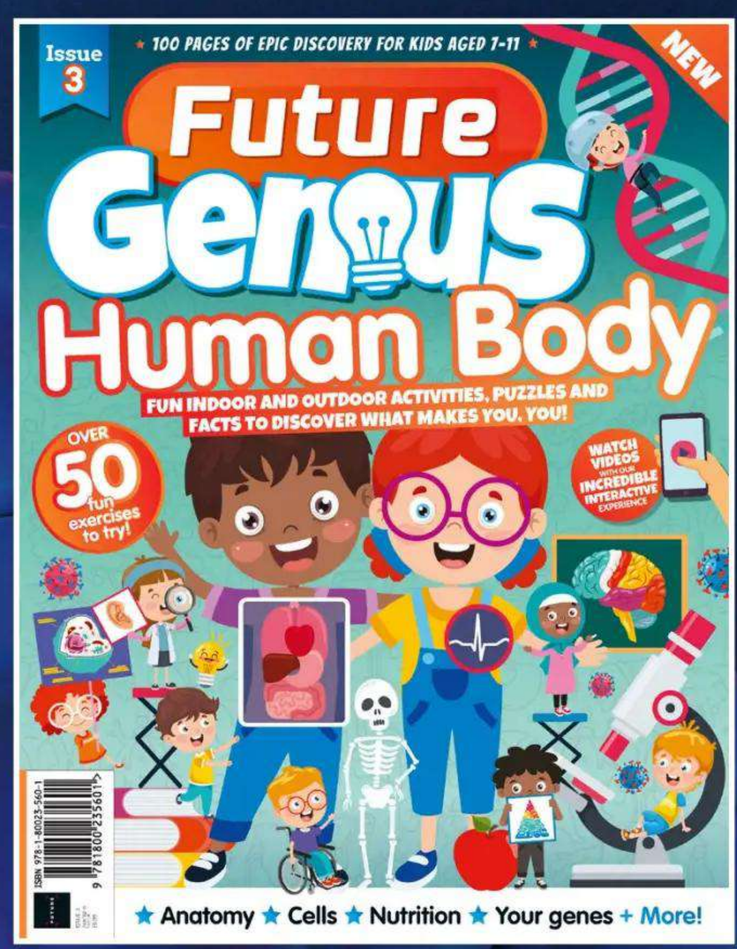


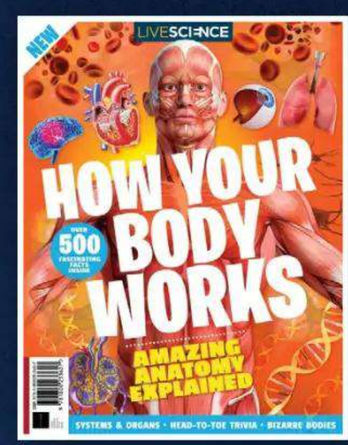
Get great savings when you buy direct from us

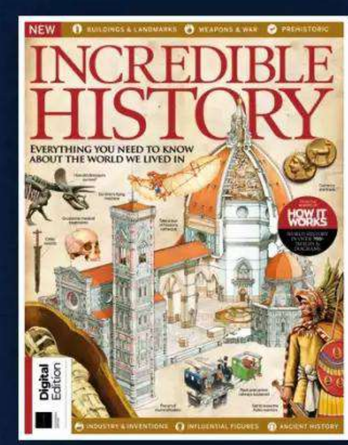
1000s of great titles, many not available anywhere else

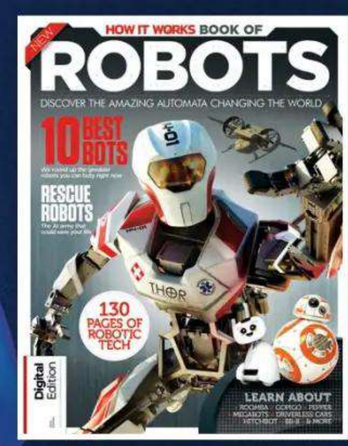
World-wide delivery and super-safe ordering



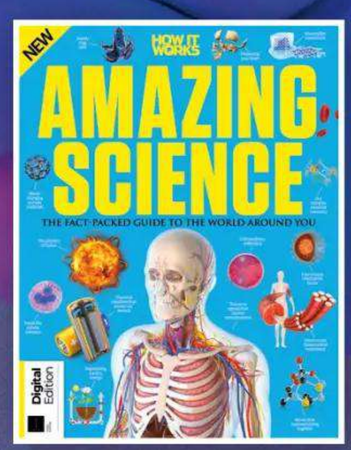



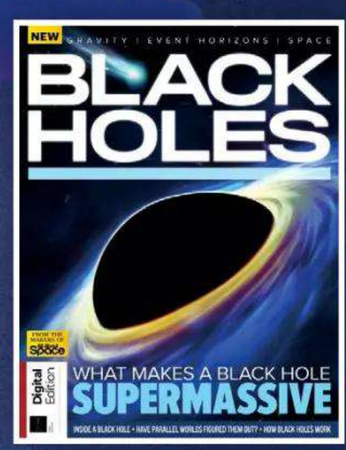



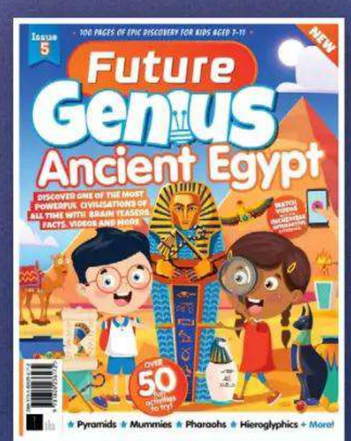


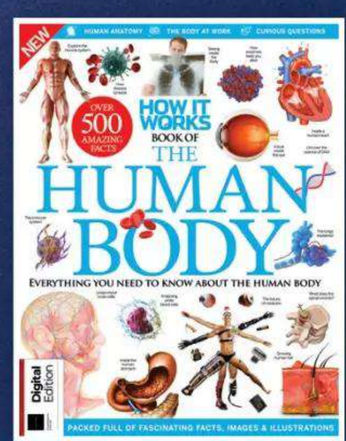
# FEED YOUR MIND WITH OUR BOOKAZINES

Explore the secrets of the universe, from the days of the dinosaurs to the miracles of modern science!










Discover answers to the most fascinating questions

**Follow us on Instagram @futurebookazines**

FUTURE

**www.magazinesdirect.com**

Magazines, back issues & bookazines.

# SUBSCRIBE & SAVE UP TO 61%

Delivered direct to your door
or straight to your device

Choose from over 80 magazines and make great savings off the store price!

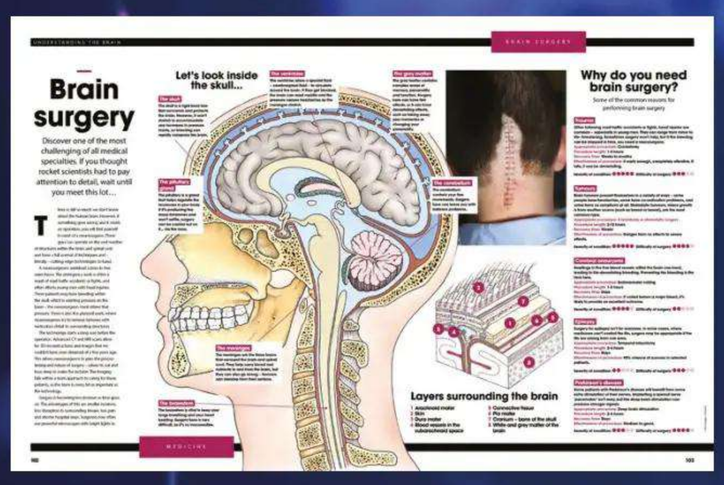
Binders, books and back issues also available

**Simply visit** www.magazinesdirect.com

No hidden costs · Shipping included in all prices · We deliver to over 100 countries · Secure online payment

FUTURE

magazinesdirect.com
Official Magazine Subscription Store




**BRAIN SURGERY**

If you thought rocket scientists had to pay attention to detail, wait until you meet this lot...

**WHY DO WE LIE?**

Deception is a product of evolution and it gives your brain a real workout

**ARE YOU SMARTER THAN...?**

How your intelligence compares to other clever members of the animal kingdom

# UNDERSTANDING The Brain

BOOKAZINE

9021